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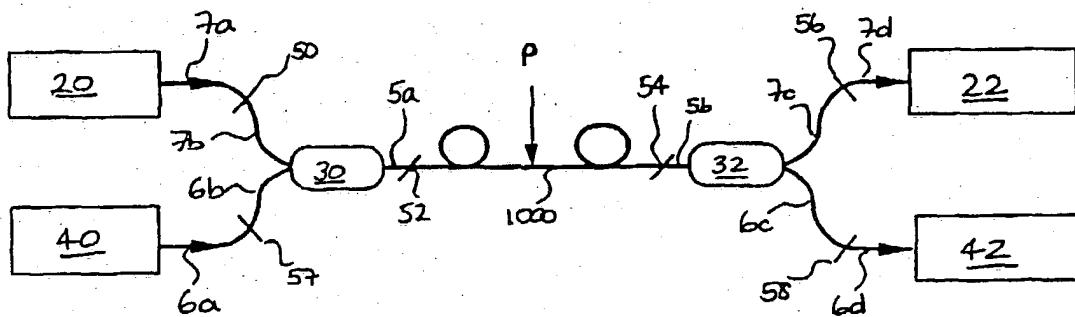
(57) Abstract

An optical waveguide system for securing live fibres against tampering and tapping off of data in optical fibre communication links is disclosed. The communication link includes a waveguide (1000) which extends from one location to another for transmitting a data signal. A data transmitter (20) launches the data signal into the fibre (1000) and a data receiver (22) receives the data signal. A sensing signal transmitter (40) launches a sensing signal into the fibre (1000) and a sensing signal receiver (42) receives the sensing signal for the fibre (1000). The transmitters (20 and 40) are coupled to the fibre (1000) by wavelengths multiplexing/demultiplexing coupler (30) via input arms (76 and 66) of the coupler (30). The signals are transferred to the receivers (22 and 42) by a further wavelength multiplexing/demultiplexing coupler (32) via output arms (7c and 6c). The couplers (30 and 32) ensure that the signals are combined with minimum power loss and are separated for transmission to the detectors also with minimum power loss and with substantially all of the data signal being transmitted to the receiver (22) and all the sensing signal being transmitted to the receiver (42).

INTRINSIC SECURING OF FIBRE OPTIC COMMUNICATION LINKS

FIELD OF THE INVENTION

This invention relates to optical waveguide systems formed

5   for securing live-fibres against tampering and tapping-off

of data in optical fibre communication links.

ART BACKGROUND

Optical devices are commonly used in industry and science

10   and include laser cavities, waveguides, lenses, filters

and other optical elements and their combinations. Such

optical devices are used in a variety of instruments and

installations.

15   Photonics technology has revolutionised the communications

and sensor fields. This is mainly due to the rapid

development of optical and opto-electronic devices. A

wide variety of glass materials, material-dopants and

waveguide structures are available and this provisional

20   specification relates to optical waveguide systems formed

for securing live-fibres against tampering and tapping-off

of data in optical fibre communication links.

Communications using an optical fibre have a number of

25   attractive features and advantages over conventional

communication means. These advantages include the

following:

• Greater bandwidth and capacity

• Electrical isolation

30   • Low error rate

• Immunity to external influences

• Immunity to interference and crosstalk

• Signal security

• Ruggedness and flexibility

35   • Potential low cost

The high expectations of optical fibres as information

carriers in communication systems have been justified by

their performance over the past two decades. Due to their high bandwidth, low attenuation and mechanical properties, each fibre is capable of replacing over 1000 copper wires in telecommunication systems. With these characteristics

5 it is no surprise that optical fibres have become the most affordable and efficient medium available in the field of telecommunications. Furthermore, the increased capacity, ease of system expandability, and reduced installation, operation and maintenance costs of the technology, is also

10 making a strong impact in industry, replacing many of the traditional communication systems.

The use of optical fibres as the main backbone of most communication systems has meant that large amounts of

15 information can be efficiently and cost effectively transferred from point to point. Modern fibre optic communications networks deploy optical fibre over millions of kilometres worldwide, carrying important and confidential information of a government, military,

20 financial and personal nature. Although it was initially thought that optical fibre transmission would be inherently secure, we now know that it is relatively easy to 'tap' information out of an optical fibre with negligible interference to the optical signal. It has

25 became obvious that in order to extract 100% of the information which is transmitted via the fibre optic cable, it is sufficient to bend the fibre only slightly or clamp onto it at any point along its length and photons of light will leak into the receiver of the intruder. Even

30 when only 0.1 dB (2%) of the signal is leaking, it will contain all of the information being transmitted in each photon. The user at the other end will never know that his information has been tampered with since they will experience no apparent interference with their

35 communications. A loss of 0.1 dB represents the lowest practical detectable optical loss in a fibre system by modern test equipment and network management systems. The

same technique could also be used in order to introduce false information or to corrupt existing information flow. This can have serious security implications for users of optical fibre communication systems, especially

5   telecommunications carriers, banks, brokerage houses, treasuries, defence organisations, government organisations, embassies and corporations, to name a few. All these information carriers and users are totally vulnerable to intrusion, tampering and tapping-off of

10   their data. This vulnerability issue has not been publicly raised to-date because suppliers and users have failed to understand the potential threat and because there have been no effective solutions. Most people today still believe that optical fibres are the most secure

15   means of communications, which is not actually true.

Until recently, the only available techniques of protection against intrusion of fibre optic telecommunications involved the use of:

20   •   encryption of the information being transmitted;
        •   physical security systems based on physical barriers (ie., thicker coatings on the fibres, thicker and harder protective jackets on the cables and housing the cables in conduits); and

25   •   static or slowly varying measurements using optical time domain reflectometers (OTDRs) to detect fibre fracture, sharp bends, fibre attenuation or connector losses.

30   Encryption techniques can be very costly, they often slow the system speed considerably/unacceptably and are not ever totally secure.

Physical security measures are not truly effective in

35   uncovering tampering with a fibre optic communications link since they require the fibre to be cut, fractured or severely bent before the problem can be detected.

OTDRs are ineffective at detecting dynamic or transient disturbances to a fibre cable. In addition, their functionality limits them to measuring only optical losses, but with relatively low sensitivity, thus they are practically limited to detecting significant and permanent or very slowly changing (and often destructive) effects on the cable.

With millions of kilometres of optical fibre deployed worldwide, the monitoring of fibre cable tampering, integrity and the prediction of the onset of failure and damage is critical to the security and reliability of fibre communication systems. Most current techniques for monitoring fibre optic cable tampering or integrity are based on static or very-slowly varying measurements using an OTDR. However, it would be a technological breakthrough to be able to obtain real-time, quasi-static and dynamic information about non-destructive disturbances anywhere along the fibre cable. This would have the further advantage of monitoring any disturbance to the cable and any structure or material near the cable or to which the cable is attached. Such a capability should also enable simultaneous, real-time fibre optic communications and sensing applications such as structural integrity monitoring, leak detection, ground monitoring, machine condition monitoring and intrusion detection.

This is possible because optical fibres can be more than mere signal carriers. Light that is launched into and confined to the fibre core propagates along the length of the fibre unperturbed unless acted upon by an external influence. Specialised sensing instrumentation may be configured such that any disturbance of the fibre which alters some of the characteristics of the guided light (ie., amplitude, phase, wavelength, polarisation, modal distribution and time-of-flight) can be monitored, and related to the magnitude of the disturbing influence.

Such modulation of the light makes possible the measurement of a wide range of events and conditions, including:
- Strain/residual strain
- displacement
- damage
- cracking
- vibration/frequency
- deformation
- impact
- acoustic emission
- liquid levels
- pressure
- temperature
- load

Fibre optic sensor technology has progressed at a rapid pace over the last decade. Different configurations of fibre sensing devices have been developed for monitoring specific parameters, each differing by the principle of light modulation. Fibre optic sensors may be intrinsic or extrinsic, depending on whether the fibre is the sensing element or the information carrier, respectively. They are designated "point" sensors when the sensing gauge length is localised to discrete regions. If the sensor is capable of sensing a measurand field continuously over its entire length, it is known as a "distributed" sensor; "quasi-distributed" sensors utilise point sensors at various locations along the fibre length. Fibre optic sensors can be transmissive or can be used in a reflective configuration by mirroring the fibre end-face.

Hence, fibre optic sensors are actually a class of sensing device. They are not limited to a single configuration and operation unlike many conventional sensors such as electrical strain gauges and piezoelectric transducers. Consequently, fibres are now replacing the role of

conventional electrical devices in sensing applications to the extent where we are now seeing a multitude of sensing techniques and applications being explored for practical gain.

5

However, to-date most fibre optic sensor systems are based on point sensing devices, thus requiring a large number of sensors to cover a large area or long length of interest. The subsequent cost and complexity of such systems is most

10 often restrictive or impractical.

Very few distributed techniques have been developed and are commercially available. Of those that have been developed, most monitor only temperature and fewer still

15 have the capability to actually locate the region or position of the sensed parameter or disturbance along the fibre length; they simply detect, alert and sometimes quantify that an event has occurred. Furthermore, many of these techniques are often limited to monitoring static or

20 very slowly varying parameters due to the requirement of measuring and averaging the time-of-flight of very narrow, low power back-reflected optical pulses (most are based on OTDR principles).

25 However, it would be a significant advance to be able to also obtain real-time, quasi-static and dynamic information about any form of disturbance to the optical fibre and their location, particularly transient events which are too quickly occurring to detect with OTDR

30 techniques. This can be achieved by combining a distributed sensing technique incapable of locating the events with a compatible technique that is capable of locating the events. Such a capability would enable truly distributed sensing applications such as fibre cable

35 tampering or third-party interference detection, as well as offering the further advantage of monitoring any structure or material near the fibre or to which the fibre

is attached (ie., structural integrity monitoring,
pipeline leak detection, ground monitoring, machine
condition monitoring and intrusion detection of high
security areas).

5

Our International application no. PCT/AU95/00568 discloses
fibre optic distributed vibration sensing technology. The
sensing technique was based on a unique fibre optic
modalmetric sensor configuration. This technology
10 overcomes the inherent weaknesses of most multimode fibre
optic sensors, offering truly localised, mechanically
stable and linear sensing. The sensing is achieved by
using a modalmetric interference effect, which is based on
the modulation of the modal distribution (effectively
15 changing the intensity) in a multimode optical fibre by
external perturbations. In this method, the sensor
response is a direct function of the disturbance on the
sensitive portion of the fibre. The disturbance may be in
the form of physical movement (ie., compression (radially
20 or axially), elongation, twisting, vibration, etc.) or
microphonic effects (ie., travelling stress waves or
acoustic emissions). The ability to vary the sensing
length to fit specific applications is a major and unique
advantage of this technology. This is particularly
25 relevant if long sensing lengths are required, as is the
case when combining the sensing technique with fibre optic
communications. The only limitation imposed on the
sensing length is in the optical power budget of the
system. Therefore, if a longer sensing length is desired
30 a higher power laser is required.

The system of this international application provides a
simple, effective and inexpensive technique to detect and
characterise both small and large disturbances on any
35 optical fibre cable, anywhere along its entire length, and
in real-time. This offers the capability of
simultaneously utilising a fibre optic communications

cable as a tampering-alert, intrusion-alert or integrity-testing sensing cable, thus providing continuous, real-time monitoring of the fibre cable and any structure near the cable (ie., ground, tunnels, ducts, pipes, buildings,
5   equipment, vessels, etc.).

One of the key features of the technology is its configuration-flexibility since it is wavelength independent. This makes it possible to use with any type
10   of optical fibre, thus it can be simultaneously retrofitted and integrated into any existing fibre optic communications cable, without requiring the installation and cost of a new cable.

15   Subsequently, this technology was to be capable to be operated simultaneously with a communications system within the same optical fibre or cable, adding significant value to any communications system in regard to security and enabling easy integration of the distributed sensing
20   technology into an existing fibre optic network. To achieve this, they demonstrated a wavelength multiplexed optical fibre system which can be used in both standard singlemode (9/125 μm) and standard multimode (62.5/125 μm) optical fibre systems for simultaneous communications and
25   sensing.

Figure (1) illustrates the configuration used for the demonstration of a simultaneous fibre optic communications and sensing system. The system configuration consisted of
30   the fibre link 1, either single or multi moded, with standard 3 dB (50% splitting ratio), 2x2 fibre couplers 3a, 3b at each end to allow for the multiplexing and demultiplexing of the two wavelengths at the transmitter and receiver ends, respectively. The choice of sensing
35   wavelength was important as the responsivity of the InGaAs detector 2b in the communication channel needed to be negligible at the sensing wavelength. Thus, the

communication channel 2a was chosen to operate at a
wavelength of 1300 nm whilst the sensing channel 4a was
chosen to operate at either 633 nm or 850 nm. This
ensured that inter-channel crosstalk was negligible, as
5   the Si 4b detector utilised in the sensing channel would
not respond to the 1300 nm communications signal.

Figure (2) illustrates the results from the sensing
arrangement shown in Figure (1) when a vibrational
10   disturbance was applied to a short section of the fibre
link. A vibrational disturbance was applied to a small
section (5 cm) of the fibre link using a cantilever beam
arrangement. The fibre was simply taped longitudinally
along the beam length. A typical sensor response is shown
15   in Figure (2a) for a 28 km singlemode (SM) link and in
Figure (2c) for a 53 km multimode (MM) fibre link. As can
be seen, very good signal quality was obtained. In
addition, the Fast Fourier Transforms (FFTs) (Figures 2b
and 2d) clearly identify the natural frequency of the beam
20   to be -18 Hz with both links.

Simultaneous, non-interfering communication and sensing
was thus successfully demonstrated on a SM optical fibre
link with a communications data rate of 50 Mb/s as well as
25   a 500MHz analog communications channel bandwidth system
using a sensing wavelength of 633 nm and 850 nm,
respectively.

While this technology had proven itself effective for
30   securing fibre optic communications cables it still had
one significant limitation that would limit its commercial
attractiveness; it was not capable of pin-pointing the
location of the disturbance to the fibre. In order to
overcome this major limitation, our International
35   application no. PCT/AU99/01028 discloses a compatible
methodology and technology for locating disturbances in
fibre optic sensing systems. The technique relies on the

measurement of the time delay or difference between
transmissive counter-propagating optical signals affected
by the same event in a two-ended fibre arrangement. In
this novel arrangement, as illustrated in Figure (3),

5   continuous-wave (CW) optical signals S and S1 are
simultaneously launched, preferably from a single light
source, into opposite ends of a sensing optical fibre 1 or
set of fibres and simultaneously detected by synchronised
photodetectors. Pulsing of the optical signal is not

10 necessary, although it may be employed in some
arrangements. Any sensed parameter P which acts to alter
the counter-propagating signals will effect both signals
in the same manner, but because the effected counter-
propagating signals must each continue travelling the

15 remainder of the fibre length to their respective
photodetectors there is a resultant time delay or time
difference between the detected signals. The time delay
is directly proportional to the location of the sensed
event along the fibre length. Therefore, if the time

20 delay or difference is detected and measured, the location
of the event can be determined. At the same time, if a
compatible sensing mechanism is being employed the sensed
event can be quantified and/or identified (ie., strain,
vibration, acoustic emission, temperature transients,

25 etc.). In addition, non-sensitive fibre optic delay lines
L may be connected to the sensing fibre at either or both
ends in order to add additional delay between the
transmissive counter-propagating signals and to provide
insensitive lead fibres.

30

This technique enables dynamic and transient events to be
located in virtually any distributed fibre optic sensing
system, and its transmissive counter-propagating technique
does not possess the limitations and complexities of OTDR

35 principles.

The system has the following advantages:

•   Operates on virtually any existing type of
transmissive distributed fibre optic sensor, enabling
dynamic and transient events to be detected, quantified,
characterised and located anywhere along the length of the
5 optical fibre.

•   Operates in a transmissive configuration, thus
delivering the entire optical signal and power back to the
detector and not requiring signal averaging.

•   Determines the location of events via the time delay
10 measured between counter-propagating optical signals
effected by the same disturbance. The spatial resolution
is, therefore, limited and set by the speed of the data
acquisition system.

•   Does not require laser pulsing, although it is
15 capable of operating with pulsed techniques.

With the two above-mentioned advances , there has been
proposed one possible configuration for monitoring and
locating disturbances to a fibre optic communications
20 cable by utilising a non-active ("dark") fibre in the
cable, as illustrated in Figure (4). However, feedback
from industry has also emphasised the desire to monitor
active ("live") fibres in certain circumstances.

25 A simple solution to this requirement would be to utilise
the wavelength multiplexing method illustrated in Figure
(1). However, the use of 3 dB couplers imposes an
additional minimum optical loss of 6 dB, which could
severely impact the optical power budget of most
30 communications systems. Ultimately, it would be desirable
to implement the modalmetric sensing and the locating
techniques in such an optical arrangement that would
minimise the optical power losses to a communications
system. If, likewise, the arrangement also minimised the
35 optical power losses to the sensing system, then it would
be possible to design and configure a communications node
or junction by-pass arrangement for the sensing signal in

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order to extend the sensing fibre length beyond one
communication node.   This would be particularly useful for
ring topology networks.

5   BRIEF SUMMARY OF THE INVENTION
       The object of the present invention is to provide optical
       waveguide systems formed for securing live-fibres against
       tampering and tapping-off of data in optical fibre
       communication links, while minimising optical power losses
10   to both the communications and sensing signals.

       The present invention provides an optical waveguide
       communication link, including;
                a waveguide for conveying signals from one
15   location to another location;
                a data transmitter for launching a data signal
       at a first wavelength into the waveguide;
                a data receiver for receiving the data signal
       from the waveguide;
20   a sensing signal transmitter for launching a
       sensing signal at a second wavelength different to the
       first wavelength, into the waveguide;
                a sensing signal detector for detecting the
       sensing signal after the sensing signal has travelled
25   through the waveguide; and
                signal splitting means between the waveguide and
       the data receiver and the sensing signal detector so that
       the signal at the first wavelength is separated from the
       sensing signal at the second wavelength by the signal
30   splitting means so that substantially all of the data
       signal without significant loss and without any
       significant component of the sensing signal is directed to
       the data receiver, and substantially all of the sensing
       signal without any significant loss and without any
35   significant component of the data signal is directed to
       the sensing signal detector.

Thus, according to the invention both the sensing signal
and the communication signal can be launched into a single
waveguide and transmitted along the waveguide whereupon
the system separates the individual wavelength components
5   of the sensing signal and the data signal for transmission
to their respective data receiver and signal sensing
detector so that if both signals are received without
substantial contamination by the other signal and with
minimum optical power loses. Thus, sensitivity of the
10   transmitted data signals and sensing signals is greatly
enhanced thereby enabling proper communication of data and
also proper sensing of any attempt to interfere with the
waveguide to tap off data from the waveguide.

15   In the preferred embodiment of the invention the signal
splitting means comprises a wavelength
multiplexing/demultiplexing waveguide coupler.

According to the preferred embodiment of the invention the
20   data signal from the waveguide and the sensing signal from
the sensing signal transmitter are received by a
wavelength multiplexing/demultiplexing coupler to combine
the signals for transmission along the waveguide.

25   The utilisation of wavelength multiplexing/demultiplexing
(WDM) waveguide devices to combine and separate the
individual wavelength components of the communications and
sensing signals in the same optical fibre, minimises the
optical power losses. For example, while a typical 2x2
30   coupler splits the transmitted light in either direction
into two roughly-equal signals (50/50% power split), a WDM
coupler efficiently taps off or inserts specific
wavelengths with considerably less loss (typically ~10%).

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In one embodiment of the invention the sensing signal
transmitter and sensing signal detector are at the said
one location and said another location respectively.

5   However, in other embodiments the sensing signal
transmitter and the sensing signal detector are located
both at one or the other of the said one location or the
another location and wherein a reflector is provided for
reflecting the sensing signal back through the waveguide
10   after separation of the sensing signal from the data
signal by the signal splitting means.

Preferably the reflector comprises a reflective mirror.

15   In one embodiment the sensing signal transmitter comprises
a counter-propagating sensing signal transmitter for
launching counter-propagating sensing signals into the
waveguide and travel in opposite directions through the
waveguide to enable the position of any disturbance to the
20   waveguide to be determined by the difference between th
time a perturbing sensing event is detected in both
counter-current sensing signals.

Preferably processing means is provided for processing the
25   sensing signal to determine a change in parameter within
the signal to identify a disturbance to the waveguide
indicative of tampering with the waveguide.

In one embodiment of the invention the communication link
30   includes a plurality of communication nodes, at least one
of the nodes including a said data transmitter, a second
node including a said data receiver and a further said
data transmitter, and a third node including at least a
further said data receiver, the waveguide interconnecting
35   each of the nodes so that the sensing signal passes
through the waveguide from the first node to the third
node.

In a still further embodiment the waveguide forms a
continuous loop including a plurality of communication
nodes arranged along the loop, at least one of the loop
5   having a said sensing signal transmitter and a said
sensing signal detector.

Preferably a said signal combining means is provided for
directing a data signal from a data transmitter at one of
10 the nodes, to a said data receiver at another of the
nodes.

The present invention may also be said to reside in an
optical waveguide communication link including;
15   a waveguide for conveying signals from one
location to another location;
            a data transmitter for launching a data signal
into the waveguide;
            a first wavelength multiplexing/demultiplexing
20 waveguide device coupled to the waveguide, the waveguide
device having a first output arm and a second output arm;
            a sensing signal transmitter for launching
sensing signal having a wavelength different to the
wavelength of the data signal into the waveguide for
25 transmission with the data signal along the waveguide;
            a data receiver coupled to the first output arm
for receiving the data signal from the waveguide device;
            a sensing signal detector coupled to the second
output arm for receiving a sensing signal from the
30 waveguide device.

Preferably the waveguide device comprises a wavelength
multiplexing/demultiplexing coupler.

35 Preferably a second waveguide device is coupled to the
waveguide remote from the first waveguide device, the
second waveguide device having a first input arm and a

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second input arm, the first input arm being coupled to the
data transmitter and the second input arm being coupled to
the sensing signal transmitter so that the data signal and
the sensing signal are transmitted to the second waveguide
5   device for launching into the waveguide.

Preferably the second waveguide device is coupled to the
waveguide by an output arm which receives both the data
signal and sensing signal from the second waveguide
10   device.

Preferably the first waveguide device is coupled to the
waveguide by an input arm so that both the sensing signal
and data signal are transmitted through the input arm to
15   the first waveguide device.

Preferably the first waveguide device comprises a first
wavelength multiplexing/demultiplexing (WDM) coupler
having the input arm and the first and second output
20   arms.

Preferably the second waveguide device comprises a second
wavelength multiplexing/demultiplexing (WDM) coupler
having the first input arm, the second input arm and the
25   output arm.

Preferably the waveguide comprises an optical fibre. The
optical fibre may be a single mode fibre or a multimode
fibre.
30

In one embodiment the second output arm of the first WDM
coupler is connected to a reflector to reflect the sensing
signal back into the waveguide through the WDM coupler,
and the second input arm of the second WDM coupler is
35   connected to an ancillary coupler, the ancillary coupler
having first and second ancillary input arms, the first
ancillary input arm being connected to the sensing signal

transmitter and the second ancillary input arm being
connected to the sensing signal detector so that the
sensing signal reflected back from the reflector passes
through the first WDM coupler, and through the second WDM
5   coupler to the second input arm, through the ancillary
coupler to the second ancillary arm and then to the
sensing signal detector.

The preferred embodiment of the present invention provides
10   a waveguide system for securing live-fibres against
tampering and tapping-off of data in optical fibre
communication links, which may include:

• providing a sensing system light source operating at a
15   wavelength different to the communications system light
source;
• providing a wavelength multiplexing waveguide light
splitter or coupler (single or multi moded) which
efficiently combines the sensing and communications
20   signals into one waveguide;
• providing a silica waveguide (single or multi moded) for
receiving light from the wavelength multiplexing waveguide
light splitter or coupler, the silica waveguide being
capable of transmitting the sensing and communications
25   signals in the required manner along its length, but
particularly such that the sensing wavelength and the
waveguide characteristics satisfy the requirements of the
modalmetric sensing and locating techniques described
earlier while unaffecting the communications signal;
30   • providing a wavelength demultiplexing waveguide light
splitter or coupler (single or multi moded) which
efficiently splits or separates the sensing and
communications signals into two output waveguide ports
while minimising optical power losses to both the
35   communications and sensing signals; and
• providing detector means for detecting the sensing
signal and, if required, the counter-propagating sensing

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optical signals effected by the same parameter and for
determining the time delay or difference between the
signals in order to determine the location of the sensed
event.

5

Preferably further silica waveguides are connected to the
first silica waveguide at either or both ends in order to
provide insensitive lead waveguides and, if applicable, to
add additional delay between the transmissive counter-
10   propagating signals.

In another embodiment the sensing wavelength output port
of the wavelength demultiplexing waveguide coupler is
terminated with a reflective mirror so as to operate the
15   sensing technique in a reflective mode.   Similarly, a
mirrored waveguide could be connected to the sensing
wavelength output port of the wavelength demultiplexing
waveguide coupler.

20   If only the sensing technique is utilised, preferably the
detector means comprises:
• a photodetector for receiving the transmitted or
reflected radiation from the sensing signal in the silica
waveguide;   and
25   • processing means for receiving signals from the
photodetector and analysing the signals in order to
register the sensed events.

If the locating technique is utilised as well as the
30   sensing technique, preferably the detector means
comprises:
• first and second photodetectors for simultaneously
receiving the radiation from the counter-propagating
signals in the silica waveguide;   and
35   • processing means for receiving signals from the first
and second photodetectors and analysing the signals in
order to register the sensed events and determining the

time delay or difference between the counter-propagating
signals effected from the same disturbance, thus
determining the location of the sensed events.

5   In a preferred embodiment the silica waveguide is a
multimoded fibre at the sensing wavelength and the lead
waveguides are singlemode fibres at the sensing
wavelength.

10   In a preferred embodiment, but without limitation, the
distributed sensing technique is based on a modalmetric
technique utilising the fusion splicing of insensitive
singlemode fibre to sensitive multimode fibre.

15   In another preferred embodiment, the transmissive counter-
propagating signal method for locating events is employed,
and suitable optical devices are employed at one or both
ends of the system to detect the signals.

20   In a preferred embodiment the wavelength
multiplexing/demultiplexing (WDM) couplers are 2x1 WDM
couplers.   In other embodiments they may be any suitable
multi-port device, such as 2x2, 3x1, 4x2, etc.

25   In a preferred embodiment all the optical fibres and fibre
devices are connected by fusion splices.   In other
embodiments the optical fibres and fibre devices may be
connected by any suitable or appropriate technique, such
as mechanical splices, connectorised leads and through-
30   adaptors, etc.

In other embodiments the WDM couplers may be replaced with
alternate wavelength filtering, conditioning, combining,
splitting or directing devices.

35

In other embodiments a plurality of WDM couplers are
utilised in a ring topology network, forming junction by-

pass arrangements for the sensing signal in order to
extend the sensing fibre length beyond one communication
node.

5   Preferably the waveguide comprises at least one optical
fibre and/or at least one optical fibre device. In some
embodiments of the invention the waveguide may merely
comprise an optical fibre without any additional elements.
However, the optical fibre can include passive or active
10   elements along its length. Furthermore, the optical fibre
can include sensing elements along its length and those
sensing elements can comprise devices which will respond
to a change in the desired parameter in the environment of
application and influence the properties and
15   characteristics of the sensing electromagnetic radiation
propagating in the waveguide to thereby provide an
indication of the change in the parameter.

Preferably any suitable CW or pulsed single or multiple
20   wavelength source or plurality of sources may be employed.
In a preferred embodiment, without limitation, a CW or
pulsed coherent laser diode is utilised to supply the
optical signal. In an alternate arrangement, multiple
light sources, of the same or varying wavelengths, may be
25   used to generate the sensing signal or a plurality of
sensing signals. In other embodiments it is possible to
combine the sensing and data transmitters into one
transmitting device.

30   The preferred embodiments of the present invention offer
the potential to utilise all-fibre, low-cost optical
devices in conjunction with laser diodes, light emitting
diodes, photodetectors, couplers, WDM couplers, isolators
and filters.

35

In the preferred embodiments of the present invention any
suitable light source, coupler and photodetector

arrangement may be used with the sensor and locating
systems. In a preferred embodiment, the required optical
properties of the light source are such that light may be
launched into and propagated in the singlemode waveguide.
For localisation, the light propagated in a singlemode
fibre must remain singlemoded during the entire period of
travel in the singlemode fibre. Once the light is
launched into the multimode fibre from the singlemode
fibre, several modes may be excited and the multimoded
fibre will be sensitive to various parameters. Once the
light is launched back into the singlemode fibre from the
multimode fibre, only a single mode is supported and
travels to the optical components of the system. Lead-
in/lead-out fibre desensitisation and sensor localisation
is achieved in this manner. In practical applications,
the singlemode fibre should be made sufficiently long to
attenuate all cladding modes in order to improve the
signal-to-noise ratio. This preferred embodiment applies
for both directions of travel of the transmissive counter-
propagating optical signals.

Utilisation of properties and characteristics of the
electromagnetic radiation propagating in the waveguide
sensor enables monitoring to take place in a non-
destructive manner. Thus, the sensor is not necessarily
damaged, fractured or destroyed in order to monitor and
locate the desired parameter.

In another embodiment the multimoded fibre is replaced by
two single moded fibres and couplers and the sensing
occurs on a phase interferometric principle

In the method, according to the preferred embodiment of
the invention, electromagnetic radiation at the sensing
wavelength is launched into an optical waveguide (single
or multi moded), such as an optical fibre, from a light
source, such as a pigtailed laser diode, fibre laser or

light emitting diode, and propagates along the optical
waveguide. The optical waveguide is fusion spliced, or
otherwise connected (temporarily or permanently), to one
input arm of an optical waveguide wavelength multiplexing

5   light splitter or coupler (single or multi moded) and when
the electromagnetic radiation reaches the coupler the
electromagnetic radiation can branch out into the output
waveguide arm of the coupler. Simultaneously,
electromagnetic radiation at the communications wavelength

10   is launched into another optical waveguide (single or
multi moded), such as an optical fibre, from a light
source, such as a pigtailed laser diode, fibre laser or
light emitting diode, and propagates along the optical
waveguide. The optical waveguide is fusion spliced, or

15   otherwise connected (temporarily or permanently), to the
second input arm of the wavelength multiplexing coupler
and when the electromagnetic radiation reaches the coupl r
the electromagnetic radiation can likewise branch out into
the same output waveguide arm of the coupler as the

20   sensing signal. Thus, the wavelength multiplexing coupler
efficiently combines both the sensing and communications
signals into a single output waveguide arm. If a
wavelength multiplexing coupler with two output arms is
used then the unused arm is fractured or otherwise

25   terminated to avoid back-reflections. The output arm of
the wavelength multiplexing coupler is fusion spliced, or
otherwise connected (temporarily or permanently), directly
to the main waveguide transmission link (single or multi
moded for the communications signal and multimoded for the

30   sensing signal). Both the communications and sensing
signals propagate along the entire length of the
waveguide, without interfering with one another, until
they reach the opposite end of the link. The main
waveguide is then fusion spliced, or otherwise connected

35   (temporarily or permanently), to the input arm of a
wavelength demultiplexing coupler and when the signals
reach the coupler they are efficiently separated and

branched out into two separate output arms of the coupler.
The output arms of the wavelength demultiplexing coupler
are then terminated at appropriate photodetectors.
Appropriate electronics, signal processing schemes and

5   algorithms process the signals from the photodetectors to
obtain the desired information.

In a preferred embodiment the WDM couplers are 2x1 WDM
couplers. In other embodiments they may be any suitable

10   multi-port device, such as 2x2, 3x1, 4x2, etc.

In other embodiments a plurality of WDM couplers are
utilised to form junction by-pass arrangements for the
sensing signal in order to extend the sensing fibre length

15   beyond one communication node.

In a preferred embodiment all the optical fibres and fibre
devices are connected by fusion splices. In another
embodiment the optical fibres and fibre devices are

20   connected by any suitable or appropriate technique, such
as mechanical splices, connectorised leads and through-
adaptors, etc.

In another embodiment the sensing wavelength output port

25   of the WDM coupler is terminated with a reflective mirror
so as to operate the sensing technique in a reflective
mode. Similarly, a mirrored fibre could be connected to
the output port of the WDM coupler.

30   In another embodiment, the transmissive counter-
propagating signal method for locating events is employed,
and suitable optical devices are employed at one or both
ends of the system to detect the signals.

35   In other embodiments the WDM couplers may be replaced with
alternate wavelength filtering, conditioning, combining,
splitting or directing devices.

Preferably the instrument optical and electronic
arrangements will utilise noise minimisation techniques.

5   Preferably, all the optical and electrical components will
be located in a single instrument control box, with
individual optical fibre input/output ports.

Optical devices, electro-optic devices, acousto-optic
devices, magneto-optic devices and/or integrated optical
10   devices may also be utilised in the system.

BRIEF DESCRIPTION OF THE DRAWINGS
Preferred embodiments of the present invention will be
further illustrated, by way of example, with reference to
15   the following drawings in which:
Figure 1 shows an integrated fibre optic sensing and
communications system, utilising the modalmetric sensing
technique;
Figure 2a, Figure 2b, Figure 2c and Figure 2d are graphs
20   showing the results from the sensing arrangement shown in
Figure 1 when a vibrational disturbance was applied to a
short section of the fibre link;
Figure 3 shows the basic principle of the waveguide
transmissive counter-propagating signal method for
25   locating events in fibre optic sensing systems;
Figure 4 shows a combined fibre optic sensing and
communications arrangement, utilising a modalmetric
sensing technique and the ability to locate disturbances
formed by the method of Figure 3;
30   Figure 5 is a view showing a general embodiment of the
present invention for a transmissive sensing arrangement
operating over a singlemode optical fibre
telecommunication link;
Figure 6 is a view showing a general embodiment of the
35   invention for a reflective sensing arrangement operating
over a singlemode optical fibre telecommunication link;

Figure 7 is a view showing a general embodiment of the invention for a two-ended counter-propagating sensing and locating arrangement operating over a singlemode optical fibre telecommunication link;

5   Figure 8 is a view showing a general embodiment of the invention for a single-ended counter-propagating sensing and locating arrangement operating over a singlemode optical fibre telecommunication link;

Figure 9 is a view showing another general embodiment of
10   the invention for a transmissive sensing arrangement operating over a multimode optical fibre telecommunication link;

Figure 10 is a view showing another general embodiment of the invention for a reflective sensing arrangement
15   operating over a multimode optical fibre telecommunication link;

Figure 11 is a view showing another general embodiment of the invention for a two-ended counter-propagating sensing and locating arrangement operating over a multimode
20   optical fibre telecommunication link;

Figure 12 is a view showing another general embodiment of the invention for a single-ended counter-propagating sensing and locating arrangement operating over a multimode optical fibre telecommunication link;

25   Figure 13 is a view showing a further general embodiment of the invention, utilising a plurality of WDM couplers in a singlemode optical fibre, three-node, point-to-point network arrangement, forming a junction by-pass arrangement for the sensing signal in order to extend the
30   sensing fibre length beyond one communication node;

Figure 14 is a view showing a further general embodiment of the invention, utilising a plurality of WDM couplers in a multimode optical fibre, three-node, point-to-point network, forming a junction by-pass arrangement for the
35   sensing signal in order to extend the sensing fibre length beyond one communication node;

Figure 15 is a view showing yet another general embodiment
of the invention, utilising a transmissive sensing
arrangement and a plurality of WDM couplers in an optical
fibre ring topology network, forming several junction by-
5   pass arrangements for the sensing signal in order to
extend the overall sensing fibre length across the entire
ring topology network;   and
Figure 16 is a view showing yet another general embodiment
of the invention, utilising a counter-propagating sensing
10   and locating arrangement and a plurality of WDM couplers
in an optical fibre ring topology network arrangement,
forming several junction by-pass arrangements for the
sensing signals in order to extend the overall sensing
fibre length across the entire ring topology network.
15

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS
Preferred embodiments of the invention, without imposing
any limitations, will be further described with reference
to the above mentioned drawings. The drawings and the
20   following embodiments are provided in as general a form as
possible to avoid confusion. While it may not be
specifically stated or illustrated in the following
embodiments and drawings, in the preferred embodiments the
following features are utilised, and not intentionally
25   omitted, where appropriate:
•   the distributed sensing technique is based on a
modalmetric technique utilising the fusion splicing of
insensitive singlemode fibre to sensitive multimode fibre;
•   the transmissive counter-propagating signal method
30   for locating events is employed, where appropriate, and
suitable optical devices are employed at one or both ends
of the system to detect and process the signals;
•   further silica waveguides are connected to the main
silica waveguide communication link at either or both ends
35   in order to provide insensitive lead waveguides and, if
applicable, to add additional delay between the
transmissive counter-propagating signals;

• any suitable light source, coupler and photodetector arrangement may be used with the sensor and locating systems. In a preferred embodiment, the required optical properties of the light source are such that light may be launched into and propagated in the singlemode waveguide. For localisation, the light propagated in a singlemode fibre must remain singlemoded during the entire period of travel in the singlemode fibre. Once the light is launched into the multimode fibre from the singlemode fibre, several modes may be excited and the multimoded fibre will be sensitive to various parameters. Once the light is launched back into the singlemode fibre from the multimode fibre, only a single mode is supported and travels to the optical components of the system. Lead-in/lead-out fibre desensitisation and sensor localisation is achieved in this manner. In practical applications, the singlemode fibre should be made sufficiently long to attenuate all cladding modes in order to improve the signal-to-noise ratio. This preferred embodiment applies for both directions of travel of the transmissive counter-propagating optical signals where this technique is utilised;

• utilisation of properties and characteristics of the electromagnetic radiation propagating in the waveguide sensor enables monitoring to take place in a non-destructive manner. Thus, the sensor is not necessarily damaged, fractured or destroyed in order to monitor and locate the desired parameter;

• utilisation of all-fibre, low-cost optical devices in conjunction with laser diodes, light emitting diodes, photodetectors, couplers, WDM couplers, isolators and filters;

• the wavelength multiplexing/demultiplexing (WDM) couplers are 2x1 WDM couplers, in other embodiments they may be any suitable multi-port device, such as 2x2, 3x1, 4x2, etc.; and

•   the optical fibres and fibre devices are connected by
fusion splices. In another embodiments the optical fibres
and fibre devices are connected by any suitable or
appropriate technique, such as mechanical splices,
5   connectorised leads and through-adaptors, etc.

Figure 1 illustrates the configuration used for the
demonstration of a simultaneous fibre optic communications
and sensing system. The system configuration consisted of
10 the fibre link 1, either single or multi moded, with
standard 3 dB (50% splitting ratio), 2x2 fibre couplers 3a
and 3b at each end to allow for the multiplexing and
demultiplexing of the two wavelengths at the transmitter
2a and 4a and receiver ends 2b and 4b, respectively. The
15 choice of sensing wavelength was important as the
responsivity of the InGaAs detector 2b in the
communications channel needed to be negligible at the
sensing wavelength. Thus, the communications channel was
chosen to operate at a wavelength of 1300 nm whilst the
20 sensing channel was chosen to operate at either 633 nm or
850 nm. This ensured that inter-channel crosstalk was
negligible, as the Si detector 4b utilised in the sensing
channel would not respond to the 1300 nm communications
signal.
25

The content of our aforesaid International Application
Nos. PCT/AU95/00568 and PCT/AU99/01028 is incorporated
into this specification by this reference.

30 Figures 2a, to 2d show the results from the sensing
arrangement shown in Figure 1 when a vibrational
disturbance was applied to a short section of the fibre
link using a cantilever beam arrangement. The fibre was
simply taped longitudinally along the beam length.
35 Results are shown for a 28 km singlemode (SM) link and a
53 km multimode (MM) fibre link. As can be seen, very
good signal quality was obtained. In addition, the Fast

Fourier Transforms (FFTs) clearly identify the natural
frequency of the beam to be ~18 Hz with both links.

Figure 3 shows the basic principle of the waveguide
5   transmissive counter-propagating signal method for
locating events in fibre optic sensing systems. The
technique relies on the measurement of the time delay or
difference between transmissive counter-propagating
optical signals affected by the same event in a two-ended
10   fibre arrangement. In this novel arrangement, continuous-
wave (CW) optical signals are simultaneously launched,
preferably from a single light source, into opposite ends
of a sensing optical fibre or set of fibres and
simultaneously detected by synchronised photodetectors.
15   Any sensed parameter which acts to alter the counter-
propagating signals will effect both signals in the same
manner. However, because the effected counter-propagating
signals must each continue travelling the remainder of the
fibre length to their respective photodetectors there is a
20   resultant time delay or time difference between the
detected signals. The time delay is directly proportional
to the location of the sensed event along the fibre length
referenced from Port 1 according to the following formula:

$$Point \quad of \quad disturbance_{Port1} = \frac{d_x - (v\Delta t)}{2} \qquad (1)$$

where d_x is the total length of the optical fibre link, Δt
is the resultant time delay or time difference between the
detected signals and v is the speed of the optical signal
30   given by c/n_{fibre}, where c is the speed of light in a vacuum
$(3 \times 10^8$ m/s) and n_{fibre} is the effective refractive index of
the optical fibre.

Similarly, the point of disturbance referenced from Port 2
35   is given by:

$$Point \quad of \quad disturbance_{Port2} = \frac{d_x + (v\Delta t)}{2} \qquad (2)$$

Therefore, if the time delay or difference is detected and
measured, the location of the event can be determined. At
the same time, if a compatible sensing mechanism is being
employed the sensed event can be quantified and/or

5   identified (ie., strain, vibration, acoustic emission,
temperature transients, etc.). In addition, non-sensitive
fibre optic delay lines may be connected to the sensing
fibre at either or both ends in order to add additional
delay between the transmissive counter-propagating signals

10   and to provide insensitive lead fibres. This may assist
engineering the technique into a practical working system.

It is interesting to note that this result illustrates
that it is required to only know the length of the entire

15   fibre link, d_x , and not the respective lengths of the
various sensitive and insensitive fibre regions in the
system. This information can be easily obtained at th
design and installation stages of a project, or post-
installation by the use of an OTDR. Then, once the total

20   length is known and the time delay, Δt, is measured by the
system, it is a straight forward calculation using
Equations 1 or 2 to determine the location of the sensed
event.

25   Figure 4 shows a combined fibre optic sensing and
communications arrangement, utilising a modalmetric
sensing technique and the ability to locate disturbances
formed by the method of Figure 3. In a practical
application of this technique, it will usually be

30   desirable for both launch points of the counter-
propagating signals to be at the same physical location.
One method in which this can easily be achieved is by
using a multi-fibre cable which will effectively form a
single-ended system. In this arrangement, one singlemode

35   fibre 1 is utilised as the communications fibre, whilst
two fibres 2 and 3, one singlemode and one multimode, are
required to set-up the modalmetric intrusion sensor (event

detection and location determination) over the specified
region of interest (within sleeve 4). A perturbation P
anywhere along the multimode fibre sleeve 4 will generate
two counter-propagating perturbation signals. Measuring
5   the time difference in their respective time of arrival at
the transmitter end of the link will allow the location of
the disturbance to be determined.

Figure 5 is a view showing a general embodiment of the
10   present invention for a transmissive sensing arrangement
operating over a singlemode optical fibre
telecommunication link. With reference to Figure 5,
according to a preferred embodiment of the present
invention, coherent laser light at the sensing wavelength
15   980 nm is launched into a 980 nm singlemode optical fibre
6a from a pigtailed laser diode with optional integrated
isolator 40 and propagates along the optical fibre 6a.
The optical fibre 6a is fusion spliced 57 to one input arm
6b of a 980/1550 nm singlemode fibre optic wavelength
20   multiplexing coupler 30 and when the light at the sensing
wavelength reaches the coupler 30 it is branched out into
the output arm 5a of the coupler 30. Simultaneously,
laser light at the communications wavelength 1550 nm is
launched into a 1550 nm singlemode optical fibre 7a from a
25   pigtailed laser diode with optional integrated isolator 20
and propagates along the optical fibre 7a. The optical
fibre 7a is fusion spliced 50 to the second input arm 7b
of the 980/1550 nm singlemode fibre optic wavelength
multiplexing coupler 30 and when the light at the
30   communications wavelength reaches the coupler 30 it is
likewise branched out into the same output arm 5a of the
coupler 30 as the sensing signal. Thus, the wavelength
multiplexing coupler 30 efficiently combines both the
sensing and communications signals into a single output
35   coupler arm 5a. The output arm 5a of the wavelength
multiplexing coupler 30 is then fusion spliced 52 directly
to the main 1550 nm singlemode optical fibre transmission

link 1000. Both the communications and sensing signals
propagate along the entire length of the 1550 nm
singlemode optical fibre transmission link 1000, without
interfering with one another, until they reach the
5   opposite end of the link 1000. The 1550 nm singlemode
optical fibre transmission link 1000 is then fusion
spliced 54 to the input arm 5b of a 980/1550 nm singlemode
fibre optic wavelength demultiplexing coupler 32 and when
the signals reach the coupler 32 they are efficiently
10   separated and branched out into two separate and
respective output arms 6c and 7c of the coupler 32. The
980 nm sensing signal output arm 6c of the wavelength
demultiplexing coupler 32 is then fusion spliced 58 to a
980 nm singlemode fibre 6d pigtailed InGaAs detector 42.
15   Similarly, the 1550 nm communications signal output arm 7c
of the wavelength demultiplexing coupler 32 is then fusion
spliced 56 to a 1550 nm singlemode fibre 7d which is
connected to pigtailed InGaAs detector 22. Finally,
appropriate electronics, signal processing schemes and
20   algorithms process the signals from the photodetectors to
obtain the desired information.

Figure 6 is a view showing a general embodiment of the
invention for a reflective sensing arrangement operating
25   over a singlemode optical fibre telecommunication link.
In the embodiment of Figure 6, according to a preferred
arrangement of the present invention, coherent laser light
at the sensing wavelength 980 nm is launched into a 980 nm
singlemode optical fibre 6a from a pigtailed laser diode
30   with optional integrated isolator 40 and propagates along
the optical fibre 6a. The optical fibre 6a is fusion
spliced 60 to one input arm 6e of a 980 nm singlemode
coupler 44 and when the light at the sensing wavelength
reaches the coupler 44 it is branched out into the output
35   arm 6g of the coupler 44. If a wavelength multiplexing
coupler with two output arms is used then the unused arm
is fractured or otherwise terminated to avoid back-

reflections. The light at the sensing wavelength then
propagates along optical fibre 6g. The optical fibre 6g
is fusion spliced 62 to one input arm 6b of a 980/1550 nm
singlemode fibre optic wavelength multiplexing coupler 30
5   and when the light at the sensing wavelength reaches the
coupler 30 it is branched out into the output arm 5a of
the coupler 30. Simultaneously, laser light at the
communications wavelength 1550 nm is launched into a 1550
nm singlemode optical fibre 7a from a pigtailed laser
10   diode with optional integrated isolator 20 and propagates
along the optical fibre 7a. The optical fibre 7a is
fusion spliced 50 to the second input arm 7b of the
980/1550 nm singlemode fibre optic wavelength multiplexing
coupler 30 and when the light at the communications
15   wavelength reaches the coupler 30 it is likewise branched
out into the same output arm 5a of the coupler 30 as the
sensing signal. Thus, the wavelength multiplexing coupler
30 efficiently combines both the sensing and
communications signals into a single output coupler arm
20   5a. The output arm 5a of the wavelength multiplexing
coupler 30 is then fusion spliced 52 directly to the main
1550 nm singlemode optical fibre transmission link 1000.
Both the communications and sensing signals propagate
along the entire length of the 1550 nm singlemode optical
25   fibre transmission link 1000, without interfering with one
another, until they reach the opposite end of the link
1000. The 1550 nm singlemode optical fibre transmission
link 1000 is then fusion spliced 54 to the input arm 5b of
a 980/1550 nm singlemode fibre optic wavelength
30   demultiplexing coupler 32 and when the signals reach the
coupler 32 they are efficiently separated and branched out
into two separate and respective output arms 6c and 7c of
the coupler 32. The 1550 nm communications signal output
arm 7c of the wavelength demultiplexing coupler 32 is then
35   fusion spliced 56 to a 1550 nm singlemode fibre 7d
pigtailed InGaAs detector 22. The 980 nm sensing signal
output arm 6c of the wavelength demultiplexing coupler 32

- 34 -

is then fusion spliced 64 to a 980 nm singlemode fibre 6h
terminated with a reflective mirror 46. The sensing
signal is thus reflected back in the opposite direction
along fibres 6h, 6c, 5b, 1000, 5a, 6b and 6g, and branched

5 through coupler 44 to output arm 6f. Thus the sensing
signal propagates along the entire length of the 1550 nm
singlemode optical fibre transmission link 1000 twice,
effectively doubling sensitivity. The output arm 6f of
the coupler 44 is then fusion spliced 66 to a 980 nm

10 singlemode fibre 6d pigtailed InGaAs detector 42.
Finally, appropriate electronics, signal processing
schemes and algorithms process the signals from the
photodetectors to obtain the desired information.

15 Figure 7 is a view showing another general embodiment of
the invention for a two-ended counter-propagating sensing
and locating arrangement, according to the method shown in
Figure 3, operating over a singlemode optical fibre
telecommunication link. A 980 nm counter-propagating

20 sensing system 300 is used to launch a sensing signal in
one direction of the 1550 nm singlemode optical fibre
transmission link 1000 and the system 300 is suitably
time-synchronised with a second 980 nm counter-propagating
sensing system 320 launching a sensing signal in the

25 opposite direction of the 1550 nm singlemode optical fibre
transmission link 1000. Any disturbance P that acts to
alter the counter-propagating sensing signals along link
1000 will effect both signals in the same manner.
However, because the effected counter-propagating signals

30 must each continue travelling the remainder of the fibre
length to their respective photodetectors in systems 300
and 320 there is a resultant time delay or time difference
between the detected signals. The time delay is directly
proportional to the location of the sensed event along the

35 fibre length, as described earlier. Time synchronisation
between system 300 and 320 is important in determining the
time difference between the counter-propagating signals.

Figure 8 is a view showing yet another general embodiment
of the invention for a single-ended counter-propagating
sensing and locating arrangement, according to the method

5   shown in Figure 4, operating over a singlemode optical
fibre telecommunication link. A single-ended 980 nm
counter-propagating sensing system 350 is used to
simultaneously launch, propagate and monitor two counter-
propagating sensing signals in the 1550 nm singlemode

10 optical fibre transmission link 1000 fusion spliced 74 to
another optical fibre (single or multi moded) in the same
or nearby cable 1200. Any disturbance P that acts to
alter the counter-propagating sensing signals along links
1000 and/or 1200 will effect both signals in the same

15 manner. However, because the effected counter-propagating
signals must each continue travelling the remainder of the
fibre length to their respective photodetectors in system
350 there is a resultant time delay or time difference
between the detected signals. The time delay is directly

20 proportional to the location of the sensed event along the
fibre length, as described earlier. Time synchronisation
in this case can be easily achieved by utilising a common
signal acquisition system.

25 Figure 9 is a view showing another general embodiment of
the present invention for a transmissive sensing
arrangement operating over a multimode optical fibre
telecommunication link. With reference to Figure 9,
according to another preferred embodiment of the present

30 invention, coherent laser light at the sensing wavelength
1310 nm is launched into a 1310 nm singlemode optical
fibre 8a from a pigtailed laser diode with optional
integrated isolator 41 and propagates along the optical
fibre 8a. The optical fibre 8a is fusion spliced 84 to

35 one input arm 8b of a 850/1310 nm multimode fibre optic
wavelength multiplexing coupler 34 and when the light at
the sensing wavelength reaches the coupler 34 it is

branched out into the output arm 5c of the coupler 34.
Simultaneously, laser light at the communications
wavelength 850 nm is launched into a multimod optical
fibre 9a from a pigtailed laser diode with optional
5   integrated isolator 25 and propagates along the optical
fibre 9a. The optical fibre 9a is fusion spliced 80 to
the second input arm 9b of the 850/1310 nm multimode fibre
optic wavelength multiplexing coupler 34 and when the
light at the communications wavelength reaches the coupler
10   34 it is likewise branched out into the same output arm 5c
of the coupler 34 as the sensing signal. Thus, the
wavelength multiplexing coupler 34 efficiently combines
both the sensing and communications signals into a single
output coupler arm 5c. The output arm 5c of the
15   wavelength multiplexing coupler 34 is then fusion spliced
81 directly to the main multimode optical fibre
transmission link 1500. Both the communications and
sensing signals propagate along the entire length of the
multimode optical fibre transmission link 1500, without
20   interfering with one another, until they reach the
opposite end of the link 1500. The multimode optical
fibre transmission link 1500 is then fusion spliced 82 to
the input arm 5d of a 850/1310 nm multimode fibre optic
wavelength demultiplexing coupler 36 and when the signals
25   reach the coupler 36 they are efficiently separated and
branched out into two separate and respective output arms
8c and 9c of the coupler 36. The 1310 nm sensing signal
output arm 8c of the wavelength demultiplexing coupler 36
is then fusion spliced 88 to a 1310 nm singlemode fibre 8d
30   pigtailed InGaAs detector 43. Similarly, the 850 nm
communications signal output arm 9c of the wavelength
demultiplexing coupler 36 is then fusion spliced 83 to a
multimode fibre 9d pigtailed or receptacled Si detector
27. Finally, appropriate electronics, signal processing
35   schemes and algorithms process the signals from the
photodetectors to obtain the desired information.

Figure 10 is a view showing another general embodiment of
the invention for a reflective sensing arrangement
operating over a multimode optical fibre telecommunication
link.   In the embodiment of Figure 10, according to
5   another preferred arrangement of the present invention,
coherent laser light at the sensing wavelength 1310 nm is
launched into a 1310 nm singlemode optical fibre 8a from a
pigtailed laser diode with optional integrated isolator 41
and propagates along the optical fibre 8a.   The optical
10   fibre 8a is fusion spliced 86 to one input arm 8e of a
1310 nm singlemode coupler 45 and when the light at the
sensing wavelength reaches the coupler 45 it is branched
out into the output arm 8g of the coupler 45.   If a
coupler with two output arms is used then the unused arm
15   is fractured or otherwise terminated to avoid back-
reflections.   The light at the sensing wavelength then
propagates along optical fibre 8g.   The optical fibre 8g
is fusion spliced 87 to one input arm 8b of a 850/1310 nm
multimode fibre optic wavelength multiplexing coupler 34
20   and when the light at the sensing wavelength reaches the
coupler 34 it is branched out into the output arm 5c of
the coupler 34.   If a wavelength multiplexing coupler with
two output arms is used then the unused arm is fractured
or otherwise terminated to avoid back-reflections.
25   Simultaneously, laser light at the communications
wavelength 850 nm is launched into a multimode optical
fibre 9a from a pigtailed laser diode with optional
integrated isolator 25 and propagates along the optical
fibre 9a.   The optical fibre 9a is fusion spliced 80 to
30   the second input arm 9b of the 850/1310 nm multimode fibre
optic wavelength multiplexing coupler 34 and when the
light at the communications wavelength reaches the coupler
34 it is likewise branched out into the same output arm 5c
of the coupler 34 as the sensing signal.   Thus, the
35   wavelength multiplexing coupler 34 efficiently combines
both the sensing and communications signals into a single
output coupler arm 5c.   The output arm 5c of the

wavelength multiplexing coupler 34 is then fusion spliced
81 directly to the main multimode optical fibre
transmission link 1500. Both the communications and
sensing signals propagate along the entire length of the
5   multimode optical fibre transmission link 1500, without
interfering with one another, until they reach the
opposite end of the link 1500. The multimode optical
fibre transmission link 1500 is then fusion spliced 82 to
the input arm 5d of a 850/1310 nm multimode fibre optic
10   wavelength demultiplexing coupler 36 and when the signals
reach the coupler 36 they are efficiently separated and
branched out into two separate and respective output arms
8c and 9c of the coupler 36. The 850 nm communications
signal output arm 9c of the wavelength demultiplexing
15   coupler 36 is then fusion spliced 83 to a multimode fibre
9d pigtailed or receptacled Si detector 27. The 1310 nm
sensing signal output arm 8c of the wavelength
demultiplexing coupler 36 is then fusion spliced 88 to a
1310 nm singlemode or multimode fibre 8h terminated with a
20   reflective mirror 47. The sensing signal is thus
reflected back in the opposite direction along fibres 8h,
8c, 5d, 1500, 5c, 8b and 8g, and branched through coupler
45 to output arm 8f. Thus the sensing signal propagates
along the entire length of the multimode optical fibre
25   transmission link 1500 twice, effectively doubling
sensitivity. The output arm 8f of the coupler 45 is then
fusion spliced 89 to a 1310 nm singlemode fibre 8d
pigtailed InGaAs detector 43. Finally, appropriate
electronics, signal processing schemes and algorithms
30   process the signals from the photodetectors to obtain the
desired information.

Figure 11 is a view showing another general embodiment of
the invention for a two-ended counter-propagating sensing
35   and locating arrangement, according to the method shown in
Figure 3, operating over a multimode optical fibre
telecommunication link. A 1310 nm counter-propagating

sensing system 400 is used to launch a sensing signal in
one direction of the main multimode optical fibre
transmission link 1500 and the system 400 is suitably
time-synchronised with a second 1310 nm counter-
5   propagating sensing system 420 launching a sensing signal
in the opposite direction of the main multimode optical
fibre transmission link 1500. Any disturbance that acts
to alter the counter-propagating sensing signals along
link 1500 will effect both signals in the same manner.
10   However, because the effected counter-propagating signals
must each continue travelling the remainder of the fibre
length to their respective photodetectors in systems 400
and 420 there is a resultant time delay or time difference
between the detected signals. The time delay is directly
15   proportional to the location of the sensed event along the
fibre length, as described earlier. Time synchronisation
between system 400 and 420 is important in determining the
time difference between the counter-propagating signals.

20   Figure 12 is a view showing another general embodiment of
the invention for a single-ended counter-propagating
sensing and locating arrangement, according to the method
shown in Figure 4, operating over a multimode optical
fibre telecommunication link. A single-ended 1310 nm
25   counter-propagating sensing system 450 is used to
simultaneously launch, propagate and monitor two counter-
propagating sensing signals in the main multimode optical
fibre transmission link 1500 fusion spliced 94 to another
optical fibre (single or multi moded) in the same or
30   nearby cable 1700. Any disturbance that acts to alter the
counter-propagating sensing signals along links 1500
and/or 1700 will effect both signals in the same manner.
However, because the effected counter-propagating signals
must each continue travelling the remainder of the fibre
35   length to their respective photodetectors in system 450
there is a resultant time delay or time difference b tween
the detected signals. The time delay is directly

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proportional to the location of the sensed event along the
fibre length, as described earlier. Time synchronisation
in this case can be easily achieved by utilising a common
signal acquisition system.

5

Figure 13 is a view showing a further general embodiment
of the invention, utilising a plurality of WDM couplers in
a singlemode optical fibre, three-node, point-to-point
network arrangement, forming a junction by-pass

10   arrangement for the sensing signal in order to extend the
sensing fibre length beyond one communication node. With
reference to Figure 13, according to a further preferred
embodiment of the present invention, starting at
Communications Node 1 N1 coherent laser light at the

15   sensing wavelength 980 nm is launched into a 980 nm
singlemode optical fibre 16a from a pigtailed laser diode
with optional integrated isolator 140 and propagates along
the optical fibre 16a. The optical fibre 16a is fusion
spliced 157 to one input arm 16b of a 980/1550 nm

20   singlemode fibre optic wavelength multiplexing coupler 130
and when the light at the sensing wavelength reaches the
coupler 130 it is branched out into the output arm 15a of
the coupler 130. Simultaneously, at Communications Node 1
laser light at the communications wavelength 1550 nm is

25   launched into a 1550 nm singlemode optical fibre 17a from
a pigtailed laser diode with optional integrated isolator
120 and propagates along the optical fibre 17a. The
optical fibre 17a is fusion spliced 150 to the second
input arm 17b of the 980/1550 nm singlemode fibre optic

30   wavelength multiplexing coupler 130 and when the light at
the communications wavelength reaches the coupler 130 it
is likewise branched out into the same output arm 15a of
the coupler 130 as the sensing signal. Thus, the
wavelength multiplexing coupler 130 efficiently combines

35   both the sensing and communications signals into a single
output coupler arm 15a. The output arm 15a of the
wavelength multiplexing coupler 130 is then fusion spliced

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152 directly to the main 1550 nm singlemode optical fibre
transmission link 2000.   Both the communications and
sensing signals propagate along the entire length of the
1550 nm singlemode optical fibre transmission link 2000,
5   without interfering with one another, until they reach the
opposite end of the link 2000.   The 1550 nm singlemode
optical fibre transmission link 2000 is then fusion
spliced 154 to the input arm 15b of a 980/1550 nm
singlemode fibre optic wavelength demultiplexing coupler
10   132 and when the signals reach the coupler 132 they are
efficiently separated and branched out into two separate
and respective output arms 16c and 17c of the coupler 132.
The 1550 nm communications signal output arm 17c of the
wavelength demultiplexing coupler 132 is then fusion
15   spliced 156 to a 1550 nm singlemode fibre 17d pigtailed
InGaAs detector 122 at Communications Node 2 N2, where
appropriate electronics, signal processing schemes and
algorithms process the signals from the photodetector 122
to obtain the desired communications information.   The 980
20   nm sensing signal output arm 16c of the wavelength
demultiplexing coupler 132 is then fusion spliced 158 to a
980 nm or 1550 nm singlemode optical fibre 2001 which acts
to by-pass Communications Node 2 so that the sensing
signal continuous propagating towards Communications Node
25   3 N3.   Continuing on, the sensing signal thus propagates
along junction by-pass fibre 2001 until fibre 2001 is
fusion spliced 257 to one input arm 116b of a 980/1550 nm
singlemode fibre optic wavelength multiplexing coupler 230
and when the light at the sensing wavelength reaches the
30   coupler 230 it is branched out into the output arm 115a of
the coupler 230.   Simultaneously, at Communications Node 2
laser light at the communications wavelength 1550 nm is
launched into a 1550 nm singlemode optical fibre 117a from
a pigtailed laser diode with optional integrated isolator
35   220 and propagates along the optical fibre 117a.   The
optical fibre 117a is fusion spliced 250 to the second
input arm 117b of the 980/1550 nm singlemode fibre optic

wavelength multiplexing coupler 230 and when the light at
the communications wavelength reaches the coupler 230 it
is likewise branched out into the same output arm 115a of
the coupler 230 as the sensing signal. Thus, the
5   wavelength multiplexing coupler 230 efficiently combines
both the sensing and communications signals into a single
output coupler arm 115a. The output arm 115a of the
wavelength multiplexing coupler 230 is then fusion spliced
252 directly to the second main 1550 nm singlemode optical
10   fibre transmission link 2002. Both the communications and
sensing signals propagate along the entire length of the
1550 nm singlemode optical fibre transmission link 2002,
without interfering with one another, until they reach the
opposite end of the link 2002. The 1550 nm singlemode
15   optical fibre transmission link 2002 is then fusion
spliced 254 to the input arm 115b of a 980/1550 nm
singlemode fibre optic wavelength demultiplexing coupler
232 and when the signals reach the coupler 232 they are
efficiently separated and branched out into two separate
20   and respective output arms 116c and 117c of the coupler
232. The 1550 nm communications signal output arm 117c of
the wavelength demultiplexing coupler 232 is then fusion
spliced 256 to a 1550 nm singlemode fibre 117d pigtailed
InGaAs detector 222 at Communications Node 3. Similarly,
25   the 980 nm sensing signal output arm 116c of the
wavelength demultiplexing coupler 232 is then fusion
spliced 258 to a 980 nm singlemode fibre 116d pigtailed
InGaAs detector 242. Finally, appropriate electronics,
signal processing schemes and algorithms at Communications
30   Node 3 process the signals from the photodetectors to
obtain the desired information. In this method, the
sensing signal was propagated along two optical fibre
links 2000 and 2002, while still utilising only one
transmitter 140 end and one detector 242 end.
35   At the 980 nm sensing wavelength it is possible to also
use true multimode fibre in place of the singlemode fibres

2000, 2001 and 2002 if the communications system was
operating over a multimode link.

5   Figure 14 is a view showing a further general embodiment
       of the invention, utilising a plurality of WDM couplers in
       a multimode optical fibre, three-node, point-to-point
       network, forming a junction by-pass arrangement for the
       sensing signal in order to extend the sensing fibre length
       beyond one communication node. With reference to Figure
10   14, according to a further preferred embodiment of the
       present invention, starting at Communications Node 1
       coherent laser light at the sensing wavelength 1310 nm is
       launched into a multimode optical fibre 18a from a
       pigtailed laser diode with optional integrated isolator
15   141 and propagates along the optical fibre 18a. The
       optical fibre 18a is fusion spliced 184 to one input arm
       18b of a 850/1310 nm multimode fibre optic wavelength
       multiplexing coupler 134 and when the light at the sensing
       wavelength reaches the coupler 134 it is branched out into
20   the output arm 15c of the coupler 134. Simultaneously, at
       Communications Node 1 laser light at the communications
       wavelength 850 nm is launched into a multimode optical
       fibre 19a from a pigtailed laser diode with optional
       integrated isolator 125 and propagates along the optical
25   fibre 19a. The optical fibre 19a is fusion spliced 180 to
       the second input arm 19b of the 850/1310 nm multimode
       fibre optic wavelength multiplexing coupler 134 and when
       the light at the communications wavelength reaches the
       coupler 134 it is likewise branched out into the same
30   output arm 15c of the coupler 134 as the sensing signal.
       Thus, the wavelength multiplexing coupler 134 efficiently
       combines both the sensing and communications signals into
       a single output coupler arm 15c. The output arm 15c of
       the wavelength multiplexing coupler 134 is then fusion
35   spliced 181 directly to the main multimode optical fibr
       transmission link 2150. Both the communications and
       sensing signals propagate along the entire length of the

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multimode optical fibre transmission link 2150, without
interfering with one another, until they reach the
opposite end of the link 2150. The multimode optical
fibre transmission link 2150 is then fusion spliced 182 to
5   the input arm 15d of a 850/1310 nm multimode fibre optic
wavelength demultiplexing coupler 136 and when the signals
reach the coupler 136 they are efficiently separated and
branched out into two separate and respective output arms
18c and 19c of the coupler 136. The 850 nm communications
10   signal output arm 19c of the wavelength demultiplexing
coupler 136 is then fusion spliced 183 to a multimode
fibre 19d pigtailed or receptacled Si detector 127 at
Communications Node 2, where appropriate electronics,
signal processing schemes and algorithms process the
15   signals from the photodetector 127 to obtain the desired
communications information. The 1310 nm sensing signal
output arm 18c of the wavelength demultiplexing coupler
136 is then fusion spliced 188 to a multimode or 1310 nm
singlemode optical fibre 2160 which acts to by-pass
20   Communications Node 2 so that the sensing signal
continuous propagating towards Communications Node 3.
Continuing on, the sensing signal thus propagates along
junction by-pass fibre 2160 until fibre 2160 is fusion
spliced 284 to one input arm 118b of a 850/1310 nm
25   multimode fibre optic wavelength multiplexing coupler 234
and when the light at the sensing wavelength reaches the
coupler 234 it is branched out into the output arm 115c of
the coupler 234. Simultaneously, at Communications Node 2
laser light at the communications wavelength 850 nm is
30   launched into a multimode optical fibre 119a from a
pigtailed laser diode with optional integrated isolator
225 and propagates along the optical fibre 119a. The
optical fibre 119a is fusion spliced 280 to the second
input arm 119b of the 850/1310 nm multimode fibre optic
35   wavelength multiplexing coupler 234 and when the light at
the communications wavelength reaches the coupler 234 it
is likewise branched out into the same output arm 115c of

the coupler 234 as the sensing signal. Thus, the
wavelength multiplexing coupler 234 efficiently combines
both the sensing and communications signals into a single
output coupler arm 115c. The output arm 115c of the
5   wavelength multiplexing coupler 234 is then fusion spliced
281 directly to the second main multimode optical fibre
transmission link 2170. Both the communications and
sensing signals propagate along the entire length of the
multimode optical fibre transmission link 2170, without
10   interfering with one another, until they reach the
opposite end of the link 2170. The multimode optical
fibre transmission link 2170 is then fusion spliced 282 to
the input arm 115d of a 850/1310 nm multimode fibre optic
wavelength demultiplexing coupler 236 and when the signals
15   reach the coupler 236 they are efficiently separated and
branched out into two separate and respective output arms
118c and 119c of the coupler 236. The 850 nm
communications signal output arm 119c of the wavelength
demultiplexing coupler 236 is then fusion spliced 283 to a
20   multimode fibre 119d pigtailed or receptacled Si detector
227 at Communications Node 3. Similarly, the 1310 nm
sensing signal output arm 118c of the wavelength
demultiplexing coupler 236 is then fusion spliced 288 to a
multimode or 1310 nm singlemode fibre 118d pigtailed
25   InGaAs detector 243. Finally, appropriate electronics,
signal processing schemes and algorithms at Communications
Node 3 process the signals from the photodetectors to
obtain the desired information. In this method, the
sensing signal was propagated along two optical fibre
30   links 2150 and 2170, while still utilising only one
transmitter 141 end and one detector 243 end.
Figure 15 is a view showing yet another general embodiment
of the invention, utilising a transmissive sensing
arrangement and a plurality of WDM couplers in an optical
35   fibre ring topology network, forming several junction by-
pass arrangements for the sensing signal in order to
extend the overall sensing fibre length across the entire

ring topology network. In this arrangement, ring topology
network (RTN) nodes 500, 502, 504, 506, 508 and 510 are
interconnected via optical fibre (single or multi moded)
links 600, 602, 604, 606, 608 and 610 by a logical

5   sequence of appropriate WDM couplers 550, 552, 554, 556,
558, 560, 562, 564, 566, 568, 570 and 572. Meanwhile, a
sensing signal is launched from a pigtailed laser diode
with optional isolator 520 around the network fibres 600,
602, 604, 606, 608 and 610 by the same logical sequence of

10   appropriate WDM couplers 550, 552, 554, 556, 558, 560,
562, 564, 566, 568, 570 and 572 and junction by-pass
fibres (single or multi moded) 650, 652, 654, 656 and 658
until the signal is finally received at detector 540, in a
similar fashion as that described in detail for Figures 13

15   and 14. The advantage of this arrangement is that the
overall sensing fibre length was extended across the
entire ring topology network, while still utilising only
one transmitter 520 end and one detector 540 end.
Figure 16 is a view showing yet another general embodiment

20   of the invention, utilising a counter-propagating sensing
and locating arrangement and a plurality of WDM couplers
in an optical fibre ring topology network arrangement,
forming several junction by-pass arrangements for the
sensing signals in order to extend the overall sensing

25   fibre length across the entire ring topology network. In
this arrangement, ring topology network (RTN) nodes 700,
702, 704, 706, 708 and 710 are interconnected via optical
fibre (single or multi moded) links 800, 802, 804, 806,
808 and 810 by a logical sequence of appropriate WDM

30   couplers 750, 752, 754, 756, 758, 760, 762, 764, 766, 768,
770 and 772. Meanwhile, a counter-propagating sensing
system 720 simultaneously launches counter-propagating
sensing signals around the network fibres 800, 802, 804,
806, 808 and 810 by the same logical sequence of

35   appropriate WDM couplers 750, 752, 754, 756, 758, 760,
762, 764, 766, 768, 770 and 772 and junction by-pass
fibres (single or multi moded) 850, 852, 854, 856 and 858

until the signals are finally received at synchronised
detectors in the counter-propagating sensing system 720,
in a similar fashion as that described in detail in the
other figures. The advantage of this arrangement is that
5   the overall sensing fibre length was extended across the
entire ring topology network, while utilising only a
single instrument control box, with individual optical
fibre input/output ports.

10   **APPLICATIONS OF THE PREFERRED EMBODIMENTS**
Communications using optical fibres have a number of
attractive features and advantages over conventional
communication means, and their performance has been proven
over the past two decades. The value offered by these
15   systems has now been augmented by the ability to
simultaneously monitor, in real-time, the integrity of the
cable, as well as any structure or material near the cable
or to which the cable is attached. This attractive and
useful new feature should increase the demand for the
20   technology.
Not inclusive, but indicatively, the following examples
illustrates the applications in which a combined
communications and sensing (dual) system may be used:
Any fibre optic communications systems which need to be
25   monitored against and detect intrusion, tampering or
tapping-off of information from the optical fibres, such
as:
Singlemode or multimode information technology (IT)
networks and links
30   Singlemode local area networks (LANs)
Multimode local area networks (LANs)
Singlemode wide area networks (WANs)
Multimode wide area networks (WANs)
Short-haul telecommunications
35   Long-haul telecommunications
Private fibre optic links and networks
Public fibre optic links and networks

Commercial fibre optic links and networks
Government fibre optic links and networks
Military fibre optic links and networks
Defence fibre optic links and networks
5   Embassy fibre optic links and networks
Industrial fibre optic links and networks
Financial organisation fibre optic links and networks
Any fibre optic communications systems which are also
utilised for sensing applications, including:
10   •   Public telecommunications
      •   Private telecommunications
      •   Information technology networks
      •   National security
      •   Industrial security
15   •   Law enforcement
      •   Counter-intelligence
      •   Physical perimeter security
      •   Intrusion detection & location
      •   Pipeline integrity monitoring
20   •   Pipeline third party interference detection &
location
      •   Pipeline leak detection & location
      •   Public road authorities
      •   Private road ventures
25   •   Railway authorities and freight operators
      •   Road transport operators
Any fibre optic sensing systems which are also utilised
for telecommunications, including:
      •   Public telecommunications
30   •   Private telecommunications
      •   Information technology networks
      •   National security
      •   Industrial security
      •   Law enforcement
35   •   Counter-intelligence
      •   Physical perimeter security
      •   Intrusion detection & location

- •   Pipeline integrity monitoring
- •   Pipeline third party interference detection &
location
- •   Pipeline leak detection & location
- •   Land and offshore building & construction structural
integrity monitoring & design
- •   Machine performance monitoring & design
- •   Rail stock monitoring (Flat spot detection)
- •   Power generation and transmission companies
- •   Petro-chemical & industrial plant monitoring & design
organisations
- •   Aerospace/aviation design and maintenance
organisations
- •   Public road authorities
- •   Private road ventures
- •   Railway authorities and freight operators
- •   Road transport operators
- •   Airline operators
- •   Mining companies
- •   Earthquake monitoring organisations
- •   Oceanographic companies

Since modifications within the spirit and scope of the
invention may readily be effected by persons skilled
within the art, it is to be understood that this invention
is not limited to the particular embodiments described by
way of example hereinabove.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1.   An optical waveguide communication link, including;

5   a waveguide for conveying signals from one location to another location;

                a data transmitter for launching a data signal at a first wavelength into the waveguide;

                a data receiver for receiving the data signal
10   from the waveguide;

                a sensing signal transmitter for launching a sensing signal at a second wavelength different to the first wavelength, into the waveguide;

                a sensing signal detector for detecting the
15   sensing signal after the sensing signal has travelled through the waveguide; and

                signal splitting means between the waveguide and the data receiver and the sensing signal detector so that the signal at the first wavelength is separated from the
20   sensing signal at the second wavelength by the signal splitting means so that substantially all of the data signal without significant loss and without any significant component of the sensing signal is directed to the data receiver, and substantially all of the sensing
25   signal without any significant loss and without any significant component of the data signal is directed to the sensing signal detector.

2.   The link of claim 1 wherein the signal splitting
30   means comprises a wavelength multiplexing/demultiplexing waveguide coupler.

3.   The link of claim 1 wherein the data signal from the waveguide and the sensing signal from the sensing
35   signal transmitter are received by a wavelength multiplexing/demultiplexing coupler to combine the signals for transmission along the waveguide.

4.   The link of claim 1 wherein the sensing signal
transmitter and sensing signal detector are at the said
one location and said another location respectively.

5.   The link of claim 1 wherein the sensing signal
transmitter and the sensing signal detector are located
both at one or the other of the said one location or the
another location and wherein a reflector is provided for
reflecting the sensing signal back through the waveguide
after separation of the sensing signal from the data
signal by the signal splitting means.

6.   The link of claim 5 wherein the reflector
comprises a reflective mirror.

7.   The link of any one of claims 1 to 5 wherein the
sensing signal transmitter comprises a counter-propagating
sensing signal transmitter for launching counter-
propagating sensing signals into the waveguide and travel
in opposite directions through the waveguide to enable the
position of any disturbance to the waveguide to be
determined by the difference between the time a perturbing
sensing event is detected in both counter-current sensing
signals.

8.   The link of claim 1 wherein processing means is
provided for processing the sensing signal to determine a
change in parameter within the signal to identify a
disturbance to the waveguide indicative of tampering with
the waveguide.

9.   The link of claim 1 wherein the communication
link includes a plurality of communication nodes, at least
one of the nodes including a said data transmitter, a
second node including a said data receiver and a further
said data transmitter, and a third node including at least
a further said data receiver, the waveguide

interconnecting each of the nodes so that the sensing
signal passes through the waveguide from the first node to
the third node.

5   10.   The link of claim 1 wherein the waveguide forms
a continuous loop including a plurality of communication
nodes arranged along the loop, at least one of the loop
having a said sensing signal transmitter and a said
sensing signal detector.

10

11.   A said signal combining means is provided for
directing a data signal from a data transmitter at one of
the nodes, to a said data receiver at another of th
nodes.

15

12.   An optical waveguide communication link
including;
           a waveguide for conveying signals from one
location to another location;
20   a data transmitter for launching a data signal
into the waveguide;
           a first wavelength multiplexing/demultiplexing
waveguide device coupled to the waveguide, the waveguide
device having a first output arm and a second output arm;
25   a sensing signal transmitter for launching
sensing signal having a wavelength different to the
wavelength of the data signal into the waveguide for
transmission with the data signal along the waveguide;
           a data receiver coupled to the first output arm
30 for receiving the data signal from the waveguide device;
           a sensing signal detector coupled to the second
output arm for receiving a sensing signal from the
waveguide device.

35   13.   The link of claim 12 the waveguide device
comprises a wavelength multiplexing/demultiplexing
coupler.

14.   The link of claim 12 wherein a second waveguide
device is coupled to the waveguide remote from the first
waveguide device, the second waveguide device having a
first input arm and a second input arm, the first input
5   arm being coupled to the data transmitter and the second
input arm being coupled to the sensing signal transmitter
so that the data signal and the sensing signal are
transmitted to the second waveguide device for launching
into the waveguide.
10

15.   The link of claim 14 wherein the second
waveguide device is coupled to the waveguide by an output
arm which receives both the data signal and sensing signal
from the second waveguide device.
15

16.   The link of claim 12 wherein the first waveguide
device is coupled to the waveguide by an input arm so that
both the sensing signal and data signal are transmitted
through the input arm to the first waveguide device.
20

17.   The link of claim 14 wherein the first waveguide
device comprises a first wavelength
multiplexing/demultiplexing (WDM) coupler having the input
arm and the first and second output arms.
25

18.   The link of claim 17 wherein the second
waveguide device comprises a second wavelength
multiplexing/demultiplexing (WDM) coupler having the first
input arm, the second input arm and the output arm.
30

19.   The link of any one of claims 12 to 18 wherein
the waveguide comprises an optical fibre.

20.   The link of claim 18 wherein the second output
35   arm of the first WDM coupler is connected to a reflector
to reflect the sensing signal back into the waveguide
through the WDM coupler, and the second input arm of the

second WDM coupler is connected to an ancillary coupler, the ancillary coupler having first and second ancillary input arms, the first ancillary input arm being connected to the sensing signal transmitter and the second ancillary

5   input arm being connected to the sensing signal detector so that the sensing signal reflected back from the reflector passes through the first WDM coupler, and through the second WDM coupler to the second input arm, through the ancillary coupler to the second ancillary arm

10   and then to the sensing signal detector.

21.   A method for securing live-fibres against tampering and tapping-off of data in optical fibre communication links, including:

15   providing a sensing system light source operating at a wavelength different to the communications system light source;
            providing a wavelength multiplexing waveguide light splitter or coupler (single or multi moded) which

20   efficiently combines the sensing and communications signals into one waveguide;
            providing a silica waveguide (single or multi moded) for receiving light from the wavelength multiplexing waveguide light splitter or coupler, the

25   silica waveguide being capable of transmitting the sensing and communications signals;
            providing a wavelength demultiplexing waveguide light splitter or coupler (single or multi moded) which splits or separates the sensing and communications signals

30   into two output waveguide ports while minimising optical power losses to both the communications and sensing signals; and
            detecting the sensing signal to determine if any tampering with the silica waveguide has taken place.
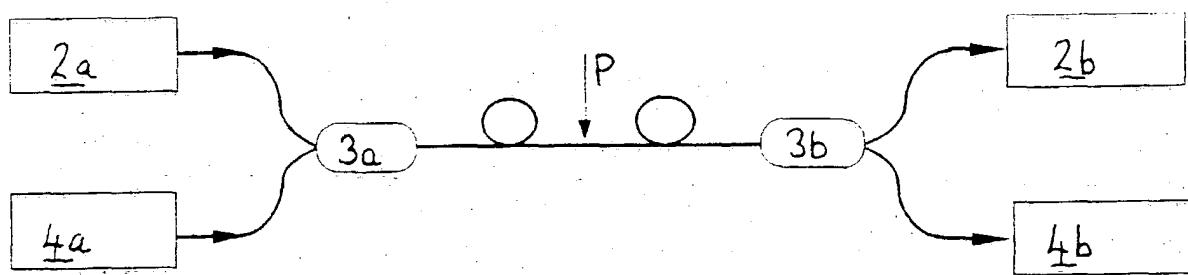
Figure 1
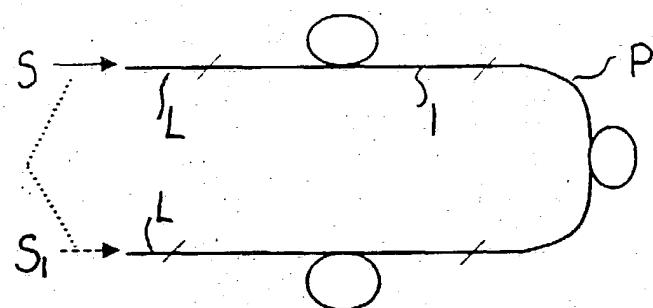
Figure 3
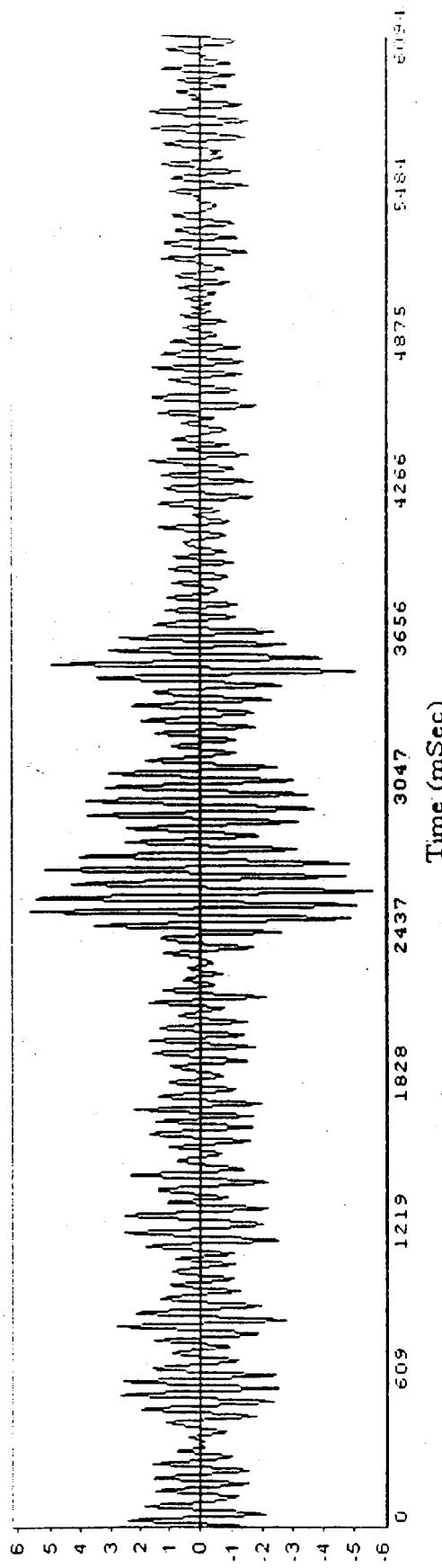
Figure 2a
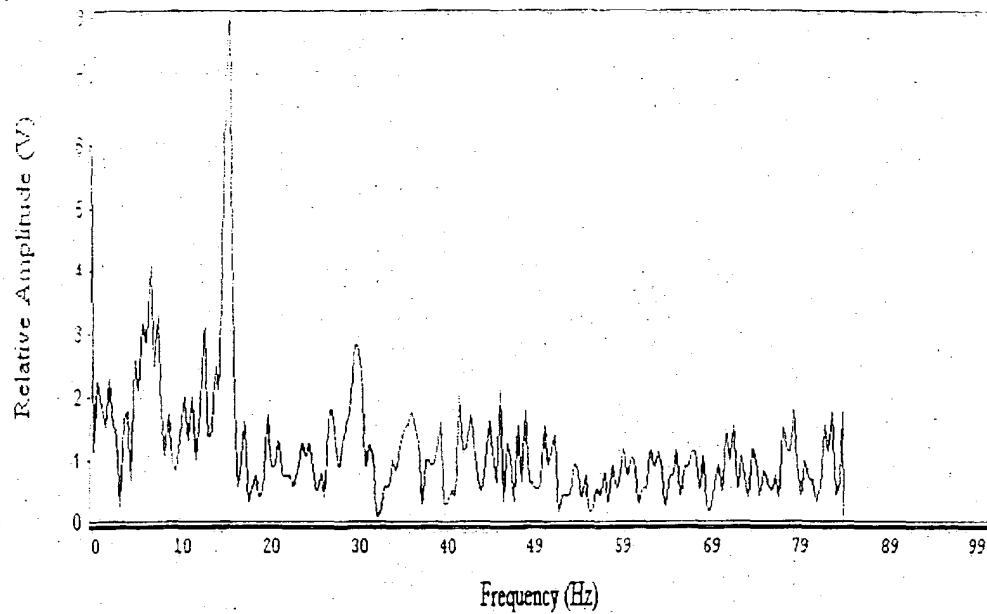
Figure 2b
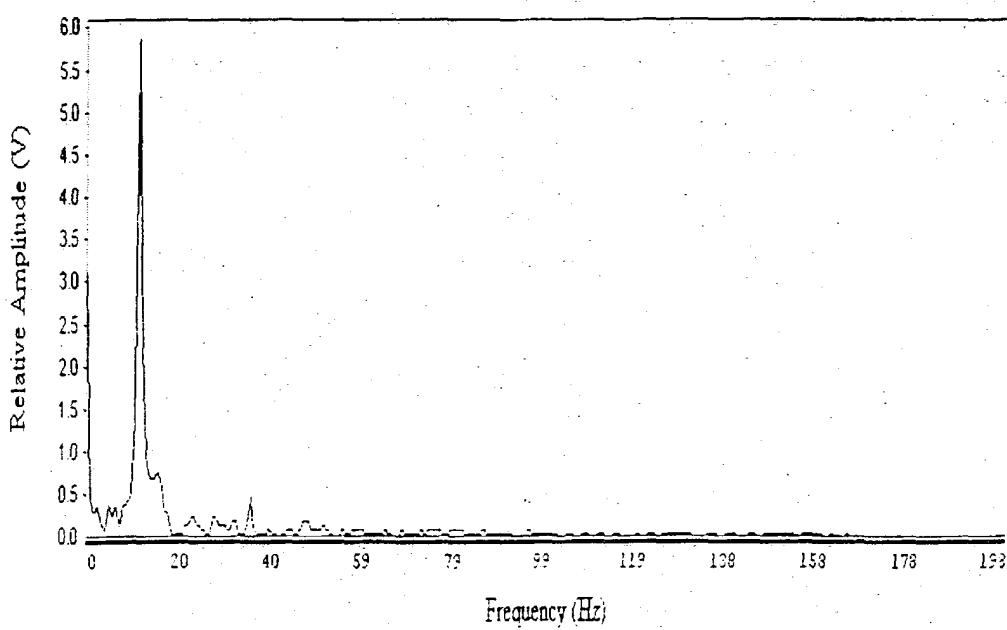
Figure 2d
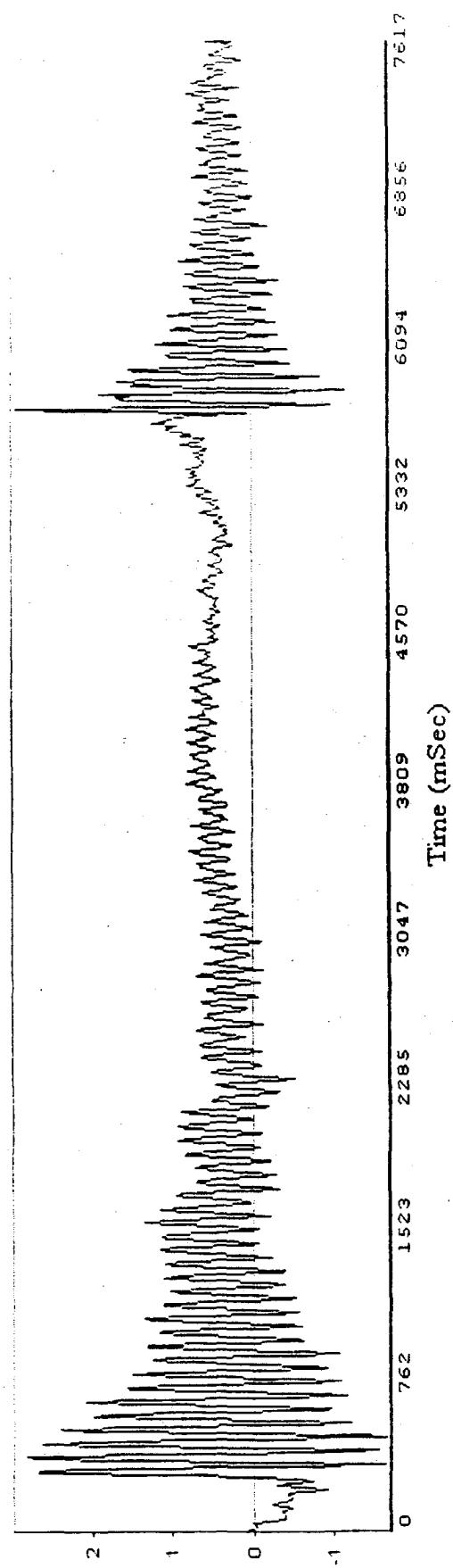
Figure 2c
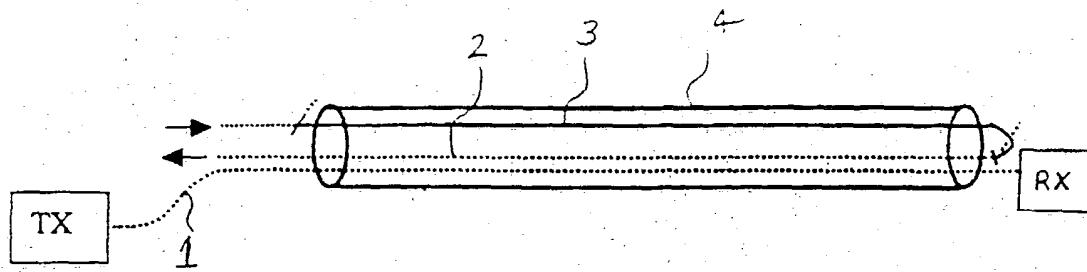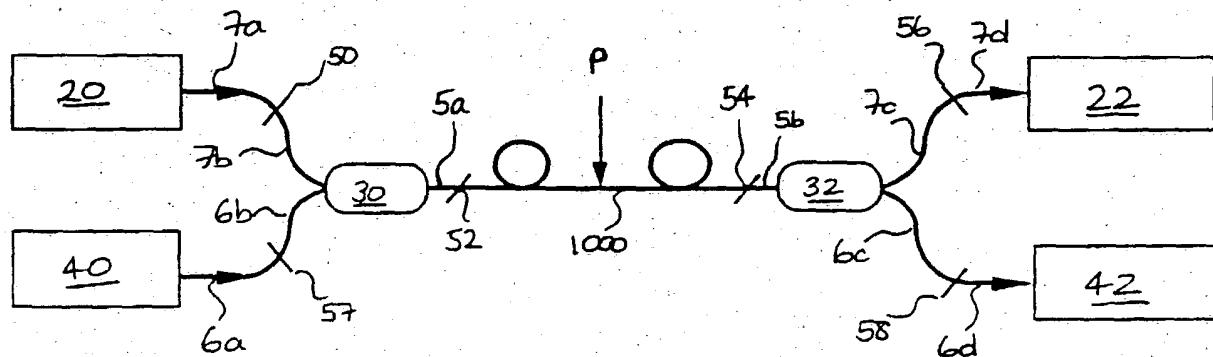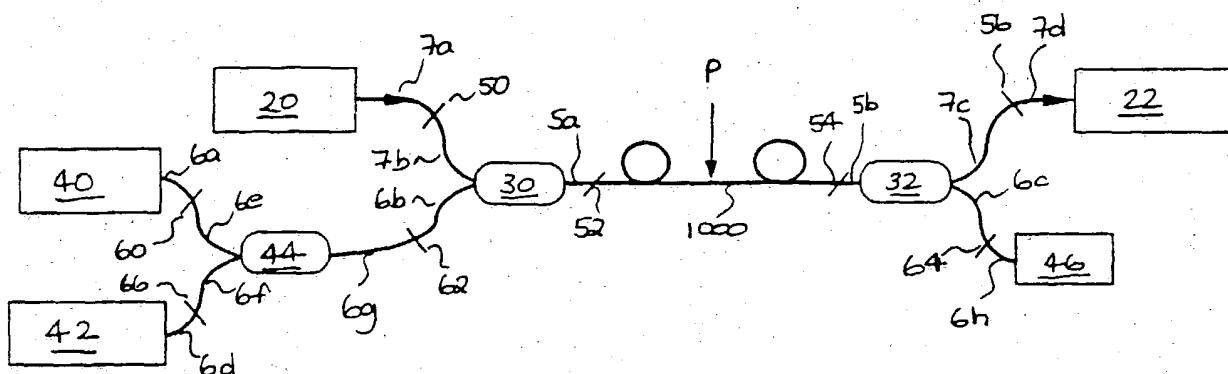
Figure 4


Figure 5

Figure 6
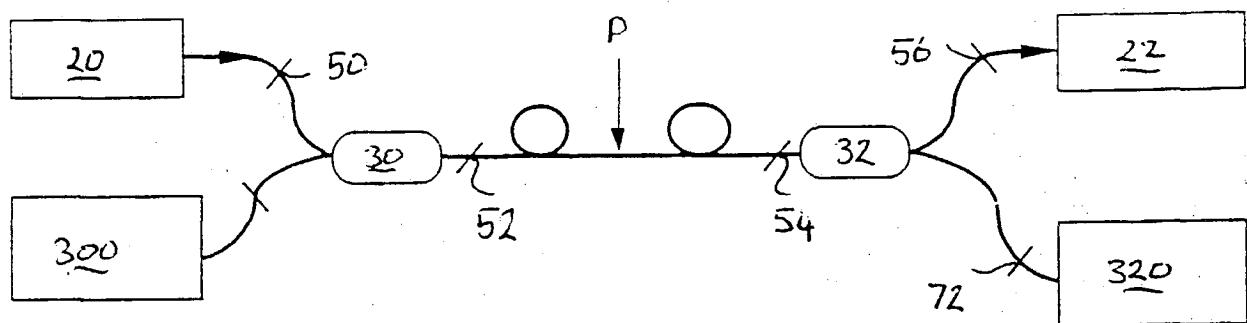
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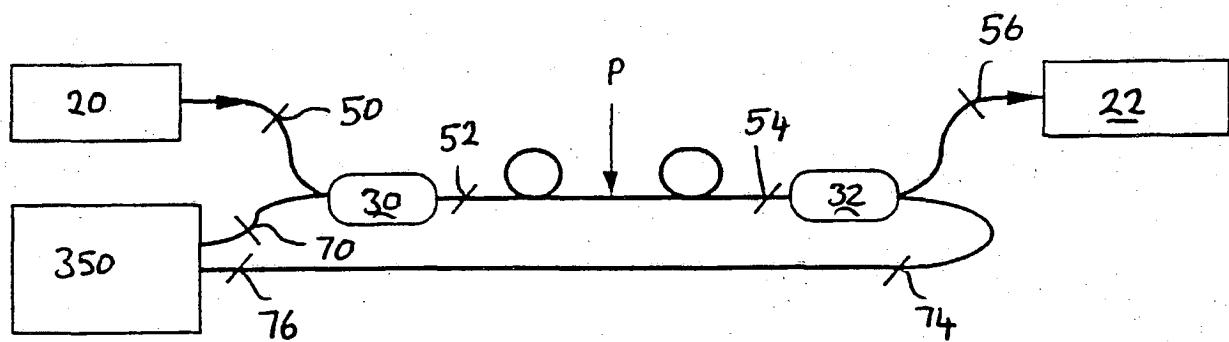
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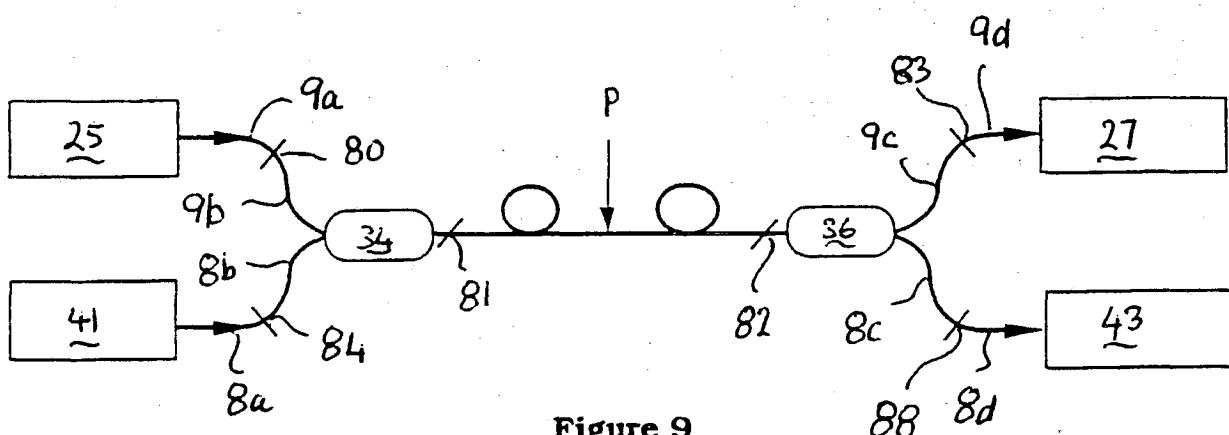
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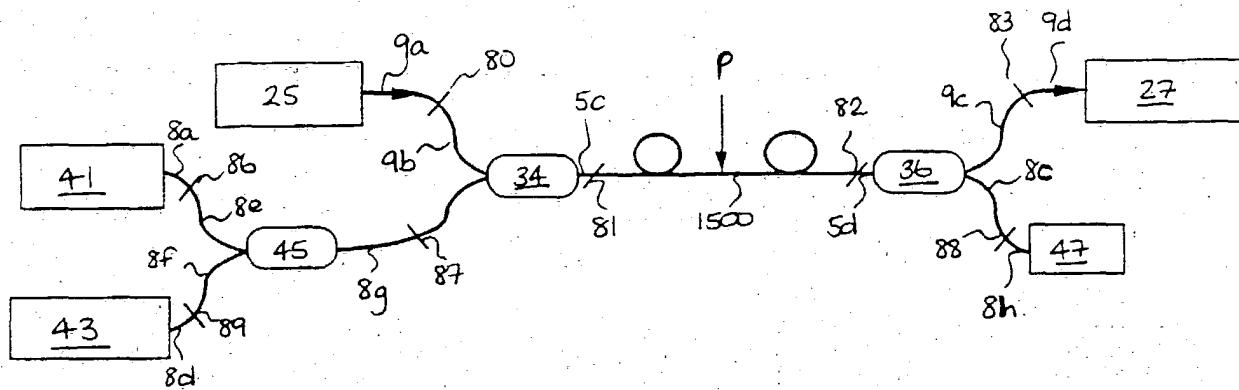
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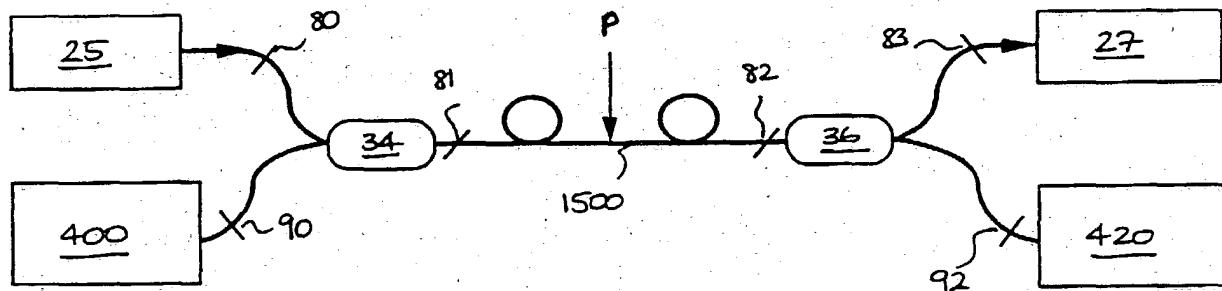
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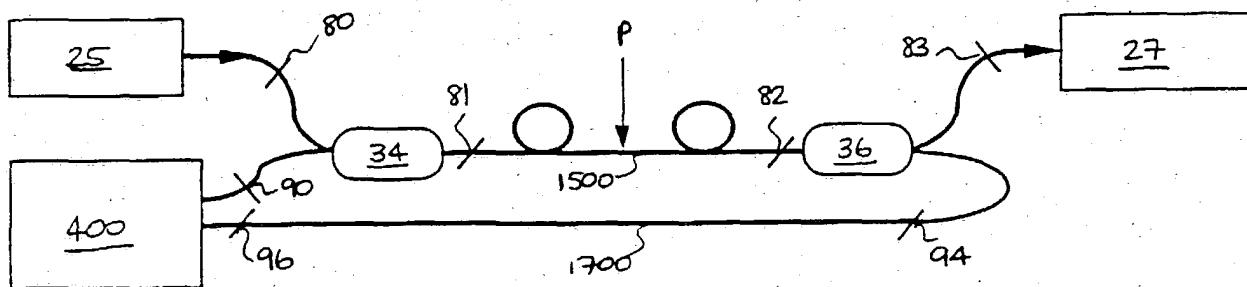
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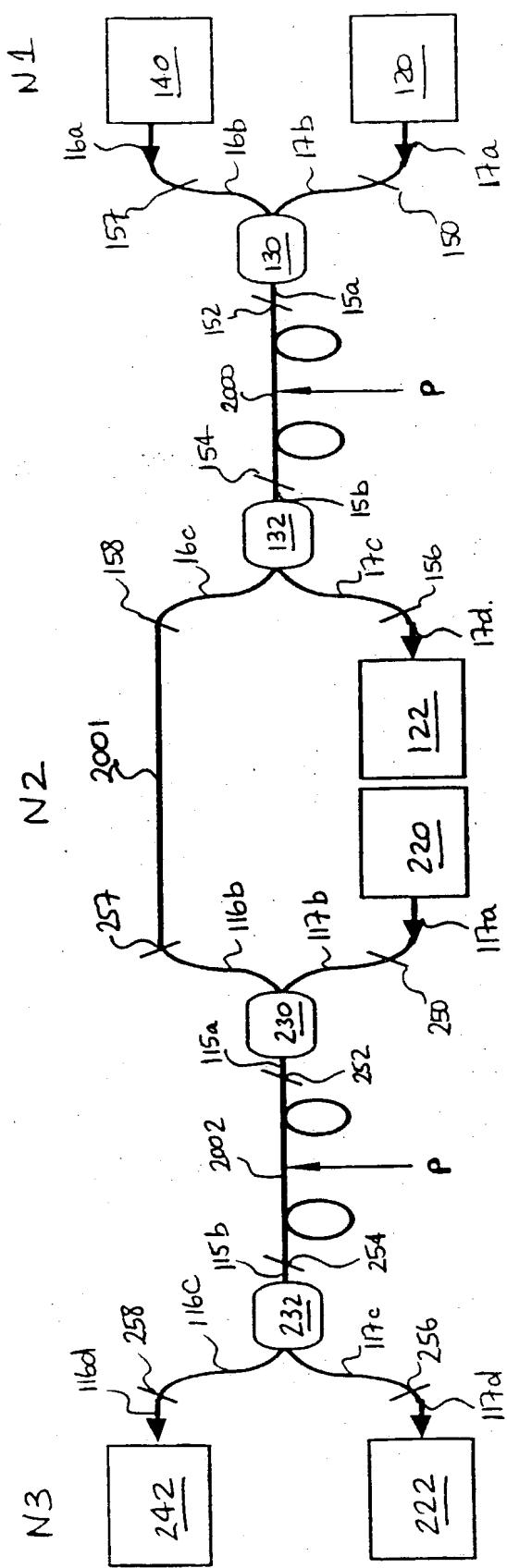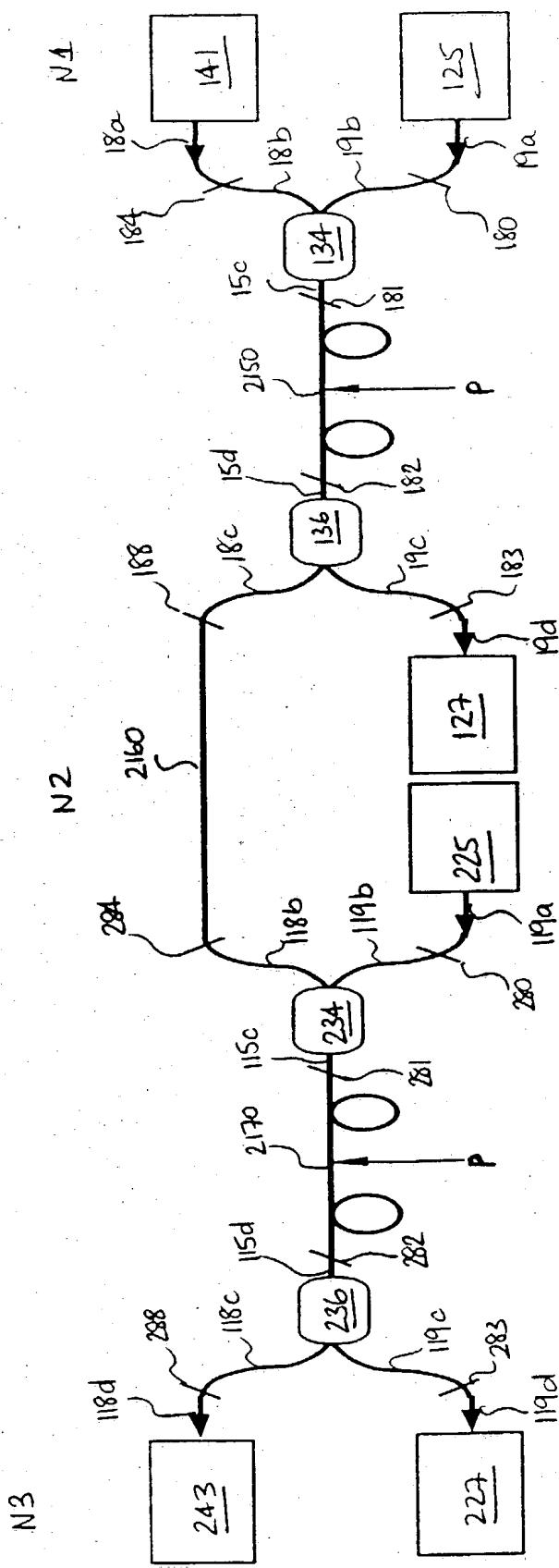
Figure 13

Figure 14
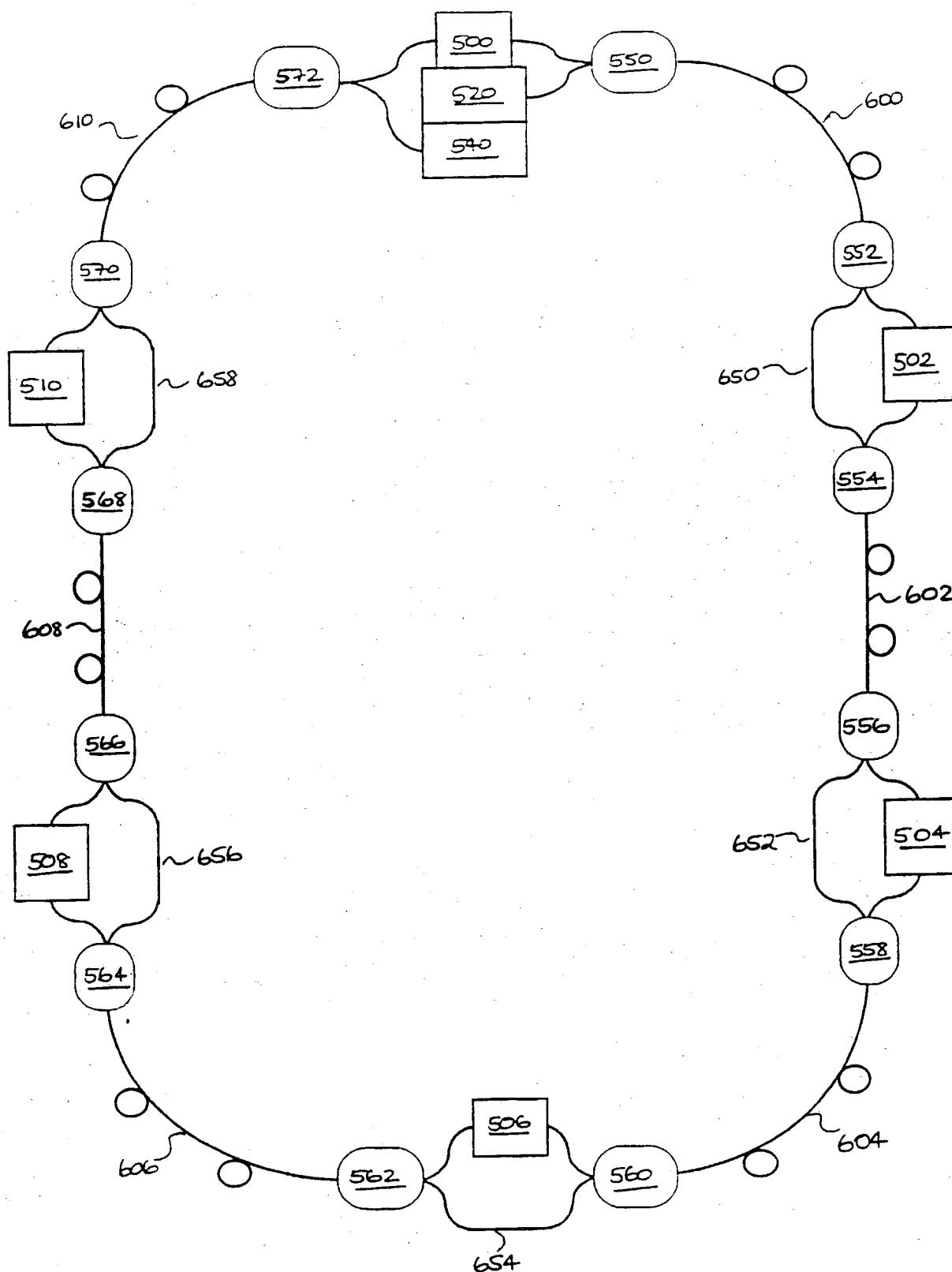
Figure 15
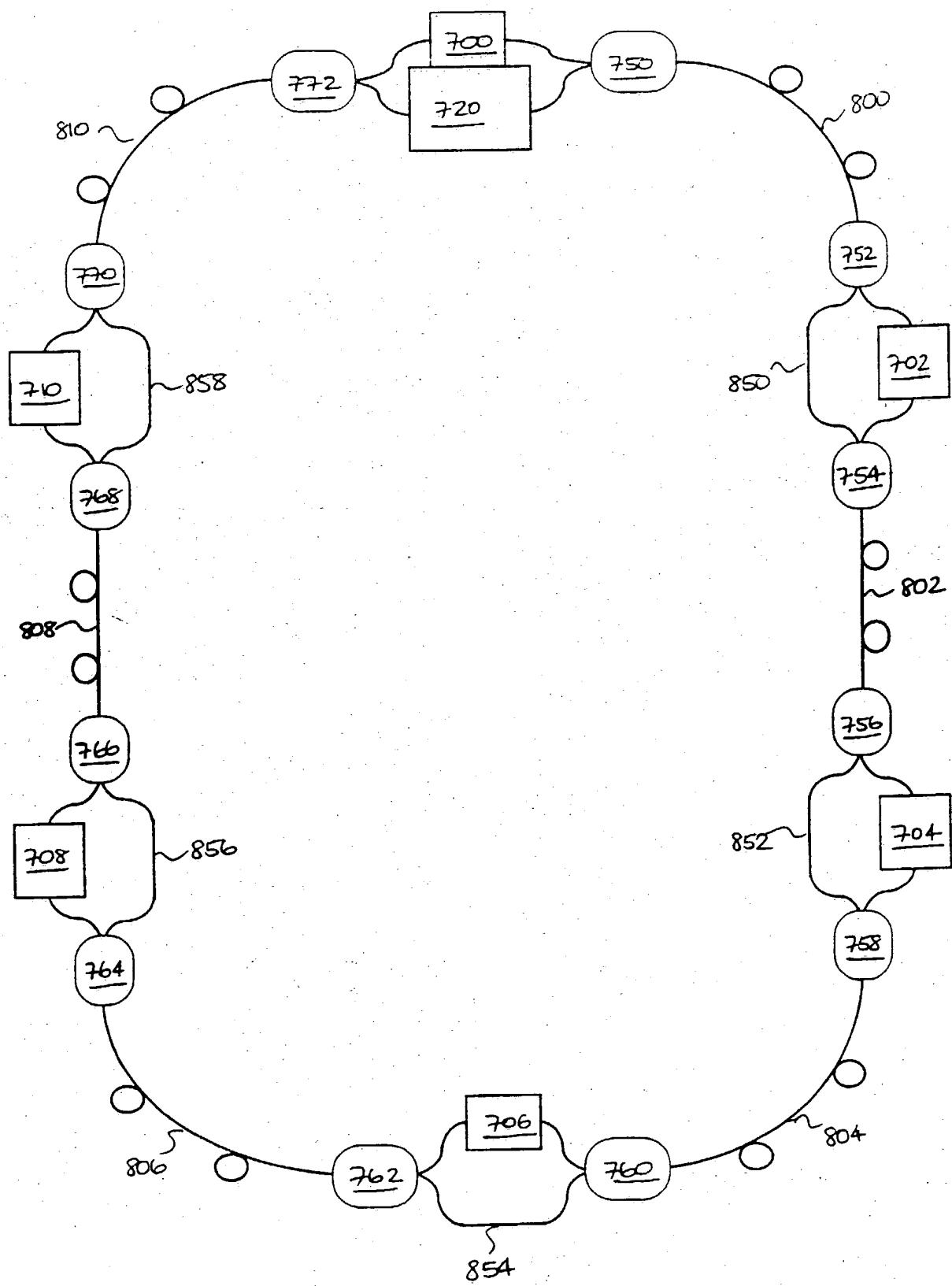
Figure 16

A.	CLASSIFICATION OF SUBJECT MATTER

Int. Cl. :   H04B 10/12, H04J 14/02, H04L 1/24

According to International Patent Classification (IPC) or to both national classification and IPC

B.	FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04J, H04B, H04L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
WPAT

C.	DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE 4427514 A (SIEMANS AG) 2 August 1996 The whole document	1-21
X Y	US 4965856 A (SWANIC) 23 October 1990 The whole document	1-21 7
Y	US 5455698 A (UDD) 3 October 1995 Column 15 line 9 - column 18 line 21	7

☐ Further documents are listed in the continuation of Box C   ☐ See patent family annex

*	Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance		
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed	"&"	document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 June 2000	05 JUL 2000
Name and mailing address of the ISA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	J. LAW Telephone No : (02) 6283 2179